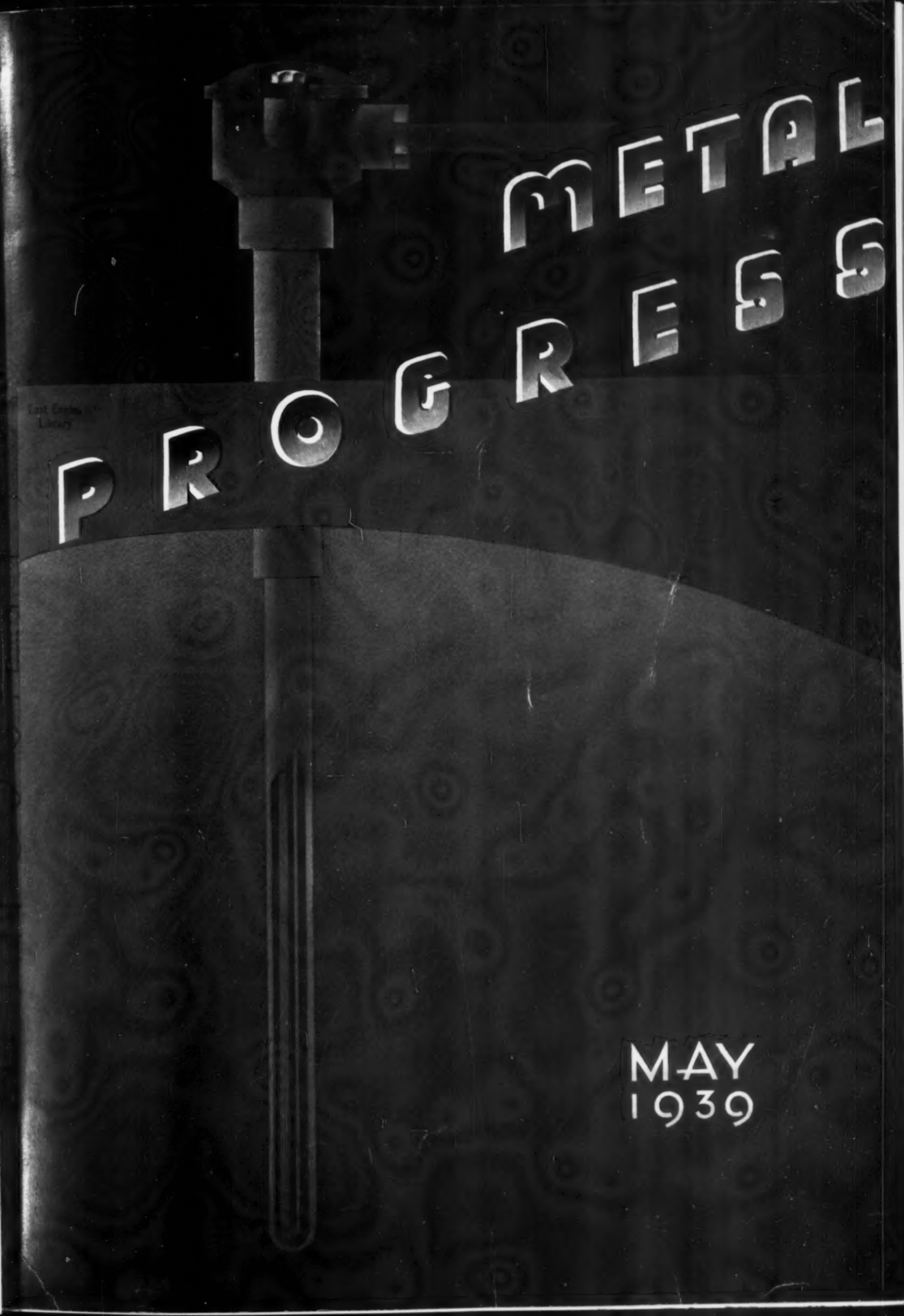
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Ernest E. Thum, Editor

May, 1939 Vol. 35, No. 5

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Control of Lead in the Steel Plant

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IT HAS BEEN DISCOVERED THAT LEAD, in concentrations as low as 0.25%, when properly distributed imparts beneficial qualities to steel. Machinability is so enhanced that increases in output of 20 to 100% and averaging around 40% have been obtained with the same equipment. The vital savings made are obtained practically without sacrifice of mechanical properties, such as tensile strength, impact resistance and hardness. This has naturally resulted in the rapid adoption of these new lead-bearing steels known as "Ledloy". Their manufacture and use has raised two questions: "What is the extent of health hazard involved?" and "How can such a hazard be controlled?" While lead is new as an alloy in steel it is not a new-comer to steel plants making terne plate or galvanized sheets.

Lead is a useful metal to man. It is found in many products of industry, such as paints, electric batteries, solders, certain brasses, bronzes and bearing metals, insecticides, glass, and "ethyl" gasolines. It is one of many toxic substances encountered in industry. Widely distributed in nature, small quantities are present in many foods that we eat and often in water that we drink. [See reference (1), listed on page 521.] No man has been found who contains no lead in his body — in fact, the human body possesses a system for eliminating lead which functions as a daily, normal process. Whether lead is harmful or not to humans depends entirely on the form in which it exists and its concentration. Iodine, for example, is a poison if too much is taken as a single dose, and yet iodine is essential to the human body — deficiency causes goiter. It is often prescribed as a medicine for other ailments.

A proper *estimation* of the extent of any health hazard must include a consideration of four major points: *(a)* Man's ability to absorb and eliminate lead, *(b)* the permissible levels of concentration in the atmosphere, *(c)* determinations of lead concentration levels encountered during manufacture, *(d)* clinical findings on the examination of men presumably exposed. A proper *control* of any health hazard so found includes a determination of the severity of exposure, the elimination of unsafe exposures, and examination of men involved by methods and at intervals adequate to indicate any absorption of lead above the ability of the system to eliminate by normal physiological processes.

It is the purpose of this article to inquire into the above points. Fortunately, it can be stated at the outset that the hazard involved is very much less than in most other industries using lead, chiefly because of the low concentration of lead in the steels to start with, and also because of the successful control of the health hazard by methods already thoroughly tested in other industries. At the Indiana Harbor plants of the Inland Steel Co., where the commercial manufacture of lead-bearing steels was first developed and has been carried on for a long time, not a single man has shown clinical evidence of any abnormal absorption of lead. It is here that all our data were obtained.

The medical profession and industrial hygienists have conclusively established the fact that lead in the form of the metal or its oxide — the two forms with which we are immediately concerned — is absorbed very little through the skin. Even if eaten, most of the lead passes on through in the feces. The major absorption occurs through the lungs. It is because of this that we are chiefly interested in the concentration of lead in the atmosphere. What is absorbed through the lungs in breathing an atmosphere with a given concentration of lead will depend upon the size of the particles. While fume, or very fine particles of condensed lead (probably as oxide in this case) has the greatest

surface area exposed, much of it is breathed right out again like tobacco smoke (2, 3).

Lead is eliminated through the feces and the urine. That which is eliminated in the feces has probably not entered into the blood or other circulating fluids of the body; it has simply passed through the alimentary canal, down through the stomach and the intestines. Even lead originally captured in the upper respiratory passages and the lungs may be lifted with mucus in the normal disposal action and swallowed. That which is absorbed by the fluids of the body may be quickly eliminated in the urine or it may be temporarily or perhaps permanently stored in the bones where it can act as Nature's balance wheel to take care of temporary large intakes of lead (4).

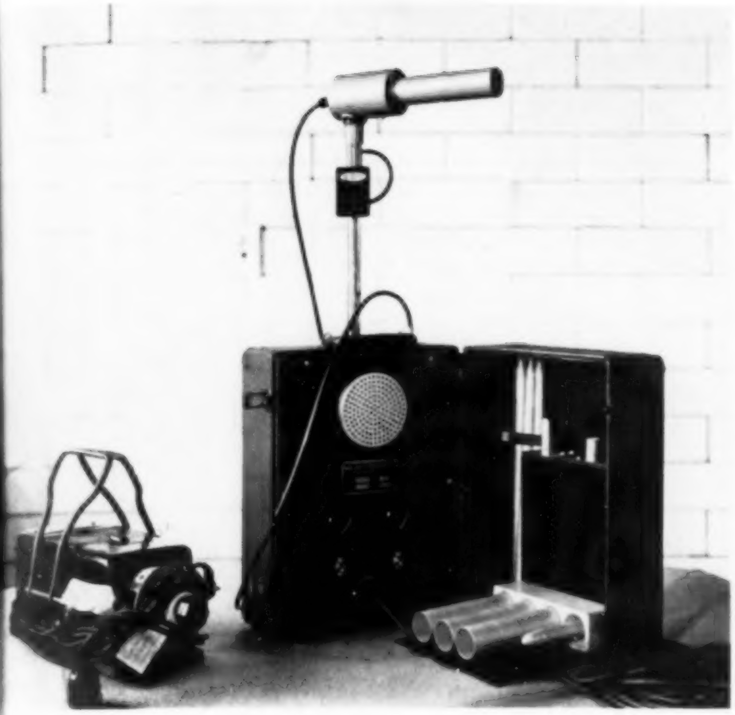
Sampling of Atmosphere for Traces of Lead is Done in Well Developed Equipment. Above are the elements of a "large" impinger set, wherein a measured amount of air is jetted through one or more baffled bottles in series. At right is equipment for passing dusty air through tubes containing a highly charged electrostatic field wherein solid or liquid particles become electrified and are drawn to the tube walls

This mechanism of absorption and elimination is functioning continuously to take care of the lead which man normally encounters in the food he eats, in the air he breathes and the water he drinks (5, 6). Lead "intoxication" results if he over-indulges and various dire consequences can result if this over-indulgence is persistent. Much has been discovered by medical research in recent years (4, 5, 6, 9, 10, 12) about the physiological effects of lead and proper treatment of cases of abnormal lead absorption. Members of the medical and safety staff must of course bring themselves up to date on these facts. An effective control to protect workers in a plant keeps the intake of lead within the quantities which can be passed on by the normal processes of elimination. The changes in the blood and the level of concentration in the urine are used as clinical measures of the level of lead absorption and analysis of the feces gives data which help to estimate the level of current lead exposure.

Realizing that man can normally eliminate a certain amount of lead, that there must be a certain level of daily intake which is safe, and further that his greatest absorption occurs from lead in the air he breathes, much work has been done to establish a "threshold value" of lead in the atmosphere. This is the level of concentration below which it is safe and above which a health hazard is presumed to exist. This threshold value is the average level of exposure for 8 hr. out of every 24. In other words, exposure during 8 hr. of every day at the average level of concentration of lead known as the threshold value will not result in absorption of lead beyond the quantity which can be eliminated by man's normal protective processes. Since a man at reasonably hard labor will breathe approximately 10 cu.m. of air a day, the threshold value is usually given as so many milligrams of lead in 10 cu.m.

The threshold value has been set by different investigators at slightly varying levels of concentration. Legge and Goadby (7) as the result of work done in England prior to 1912 set it at 5.0 mg. per 10 cu.m. Work in this country has indicated levels of 3.0 mg. per 10 cu.m. of air, and values have been set as low as 1.5 mg. Dr. R. A. Kehoe, an outstanding authority in this country, has stated (12): "In my opinion, the figure which Bloomfield and his associates [in the U. S. Public Health Service] have taken of approximately 3 mg. of lead per 10 cu.m. of air has been substantially established as the threshold of toxicity for inhaled lead." The U. S. Department of Labor has indicated 1.5 mg. per 10 cu.m. as "advised" by the U. S. Public Health Service; this lower figure seems to rest on a less secure foundation than the figure of 3.0 mg. for the metal lead or its oxides.

Whether or not a health hazard exists in the various operations involved in making Ledloy steels and the extent of any existing hazard can be indicated by proper sampling of



the atmosphere breathed by exposed men and determining the lead content.

Effective air sampling methods together with the equipment involved have been recorded in the literature (references 13 to 16) so only a brief description will be given here. In the "impinger" equipment air is sucked through absorption bottles at a measured rate by a suction pump. The particles of dust and aggregates of particles are wetted by displacing the air envelope surrounding them (17, 18). This is facilitated by impinging the stream of dust-laden air on a wetted surface where the momentum of the particles causes them to break through the air envelope and enter the liquid. Portable equipment is shown in the first engraving; normally one or two of the absorption bottles are used but in taking all of the samples reported later four were set in series to improve the recovery. In each pyrex absorption bottle 125 ml. of double-distilled water acidulated with 2 ml. of concentrated nitric acid was used as the absorbing liquid. The rate of flow of the air through the bottle must be regulated to secure efficient collection.

Two impinger equipments have been adopted by the U. S. Bureau of Mines. One is the "midget" or "small" impinger and the other is the "large" impinger. Two of the *large* equipments were used by us.

Since threshold values were originally determined with the impinger equipment, the concentration levels of lead found by us in the steel mill and elsewhere by this sampling method may be compared with the threshold value adopted. It should be pointed out that very minute particles in "fume" are not caught by the impinger equipments (17, 18). It is probable that particles small enough not to be captured—under 0.5 micron (18)—would not be caught in the lungs either (2, 3). However, to determine what lead *would* pass through the impinger absorption bottles but be caught by electrostatic precipitation, tests were also run with the impinger equipment and an electrostatic sampling equipment in series, the air first being drawn through the absorption bottles and then through the electrostatic precipitator. Very fine lead oxide particles in the air have a tendency to come together, forming aggregates. Thus the efficiency of the impinger is increased with relation to the electrostatic precipitation unit as time elapses after the formation of the fine dust or fume (17).

The quantities of lead collected are very small. One gram would raise 118,000 cu.ft. of air to the threshold value adopted. Usually a sample represents 25 to 50 cu.ft. of air drawn through the equipment and so would contain 0.0002 to 0.0004 g. if the air were at the threshold value. Great precaution must be taken to have lead-clean surfaces and lead-free material in contact with the air and absorption liquids.

Methods of Analysis

In general, the quantities of lead involved are too small for gravimetric determination, so colorimetric chemical methods with a very sensitive organic compound color reaction and spectro-chemical analysis have been resorted to. The various methods and some modification of them have been described in the technical literature listed in references 19 to 31.

A practical and accurate quantitative procedure is a modification of Fischer and Leopoldi's dithizone method (25, 26). The method used by us is that described by Winter, Robinson, Lamb and Miller (27), and is the method used in the Industrial Hygiene Laboratory of the Chrysler Corp. (28). The "mixed color" modification of Clifford and Wichmann (22, 28, 29) is not employed, although it has been found accurate. All these modifications of Fischer and Leopoldi's method use the extremely sensitive diphenyl-thiocarbazone ("di-thi-zone" for short).

By the use of the neutral wedge photometer increased speed of analysis with good accuracy has been obtained. For analyzing biological material particularly, the spectro-chemical method (30, 31) has been found accurate and expeditious.

In judging by air sampling what the exposure to workmen may be, and in comparing the results of such sampling with the threshold value, several important points must be kept in mind. The threshold value of, say, 3.0 mg. in 10 cu.m. of air means that a man may be considered to be in surroundings not hazardous to his health if he is exposed during 8 hr. out of every 24 to atmosphere containing lead in the *average* concentration of 3.0 mg. in 10 cu.m. During the 8 hr. he may be exposed for a short time to a higher concentration, but this must be balanced by a sufficient period of exposure to lower concentration. "Grab samples" taken at random have little significance except to show the concentration at a particular time at a particular place. Sampling of air in

Peak Concentrations Before Hoods Were Installed
(Mg. lead in 10 cu.m. air)

Location	Number	Highest	Lowest	Average
10-in. mill				
Near No. 8 stand	2	5.40	0.71	3.05
Discharge end of furnace	1			2.29
14-in. mill				
Near furnace	1			0.706
Near No. 1 stand	1			1.76
Near finishing rolls	1			3.18
28-in. mill				
Pulpit	1			2.47
Structural saw	1			3.18
40-in. blooming mill				
Rollers' pulpit	1			3.88
Roll stand	3	12.00	0.423	4.78
Billet dock	12	11.65	2.65	6.64
No. 2 openhearth				
No. 3 stand	1			10.24
No. 4 stand	2	17.65	10.59	14.12
Pit side	8	63.89	1.41	16.47
36-in. blooming mill				
Pulpit	12	20.83	1.37	6.00
Roll stand	17	35.30	0.42	9.64
Motor room	8	23.30	1.41	7.91
Soaking pits	1			2.60
Shears				
Control house	2	2.82	1.41	2.12
West of shears	3	1.41	0.28	0.68
South of shears	2	1.48	1.41	1.45
Billet mill				
No. 1 pulpit	2	1.06	1.06	1.06
19-in. mill				
Speed control pulpit	1			1.06
East of shears	1			3.88
No. 1 openhearth				
Balcony at pit side	16	96.72	0.39	14.4

Hourly Averages After Hoods Installed
(Mg. lead in 10 cu.m. air)

Openhearth Pouring Stand		36-In. Mill Soaking Pits
Jan. 18, 1939	Jan. 27, 1939	Jan. 27, 1939
0.233	0.208	0.159
0.328	0.543	0.292
0.547	0.773 *(a)*	0.294 *(a)*
0.123	0.552	0.677
1.458 *(a)*	0.632	0.395
0.360	0.187	0.716 *(b)*
0.276	0.434	0.116
0.219	0.095	0.219
Av. 0.443	Av. 0.424 *(c)*	Av. 0.358 *(d)*

(a) Heat of Ledloy steel poured while sample was collected.

(b) Same heat being charged into pits.

(c) Maximum results (on another date) gave 1.54 max., 0.47 min., 0.90 av. for turn at this location.

(d) Maximum results (on another date) gave 2.37 max., 0.18 min., 0.84 av. for turn at this location.

what are considered to be the locations of greatest hazard and purposely trying to get the worst conditions, has value as indicating the peak of exposure. If this is below the threshold, obviously no hazard exists. If it is found to be over the threshold value, a series of samples taken over a period of 8 hr. is necessary to determine whether or not the location is hazardous, and the time of exposure of each workman must be known to determine whether a hazard is involved.

Peak Concentrations

In an endeavor to determine where there was any possibility of the existence of a health hazard during the first months of production of Ledloy steels at Inland, all air sampling was done with the intention of measuring only peaks of concentration of lead in working environments. Samples were accordingly collected in the thickest parts of visible fume drift. Sampling periods were intentionally restricted to avoid the effect of dilution by air not heavily contaminated. The first table shows the results.

After these initial trials had shown that relatively high peak concentrations existed during the pouring of Ledloy heats, an ingenious but simple and effective exhaust system was installed. In the early stage of the development large fans were used to blow the fume away from the pouring stand, and highest concentrations were found directly in the drift of fume which was sampled

on the balconies of the pit side of the furnaces. After the installation of the exhaust system, the maximum exposure point shifted to the pouring stands and even there the peak concentrations were much lower than they had been when fans were used. This is shown by 11 samples taken in No. 1 openhearth shop next to men adding lead to ingot molds during the pouring of a leaded heat; highest peak was 10.94, lowest peak was 2.12, and average peak was 4.62 mg. per 10 cu.m. In No. 2 openhearth

Sampling the Air Near an Openhearth Furnace With Impinger Epuipment

one sample was taken following along with the men adding lead as they moved from ingot mold to ingot mold; this showed 1.41 mg. per 10 cu.m. of air.

Following the location of peak exposure points, a series of tests was made over continuous 8-hr. periods at many locations. Samples were taken continuously during each hour with the large impinger equipments. Illustrative examples of the results obtained are shown in the second table. All results of sampling the air in the openhearth department after installing the exhaust equipment have indicated that concentrations are well below the threshold value.

There are two blooming mills at Indiana Harbor on which Ledloy steel is rolled. The 36-in. mill building is an old one and is hemmed in by adjoining structures. Its natural ventilation is considerably less than is customarily found in blooming mills. The 40-in. blooming mill is modern and the ventilation is of the quantity one would expect to find in a mill of ordinary construction and not too close to other buildings. Naturally, therefore, the concentrations of lead in the atmosphere at the latter mill were considerably lower than those at the 36-in. mill. Representative figures for the metallurgists' platform in the 36-in. mill show 4.91 mg. lead per 10 cu.m. air during pouring of Ledloy heats and 0.03 minimum at in-between periods, or an average of 0.71. Maxima in the rollers' pulpit were 6.35, 5.68 and 5.68 on three days recently; corresponding minima were 0.12, 0.02, and 0.10, and the respective averages were 1.40, 1.06 and 1.10 mg. per cu.m. If found necessary, the pulpit and metallurgists' observation post in this mill could be kept under positive pressure, thus preventing infiltration of contaminated air, by blowing air into the room from out-of-doors (through a unit-type heater in winter). However the continuous sampling over the working period of 8 hr. indicates that no hazard exists under present conditions.

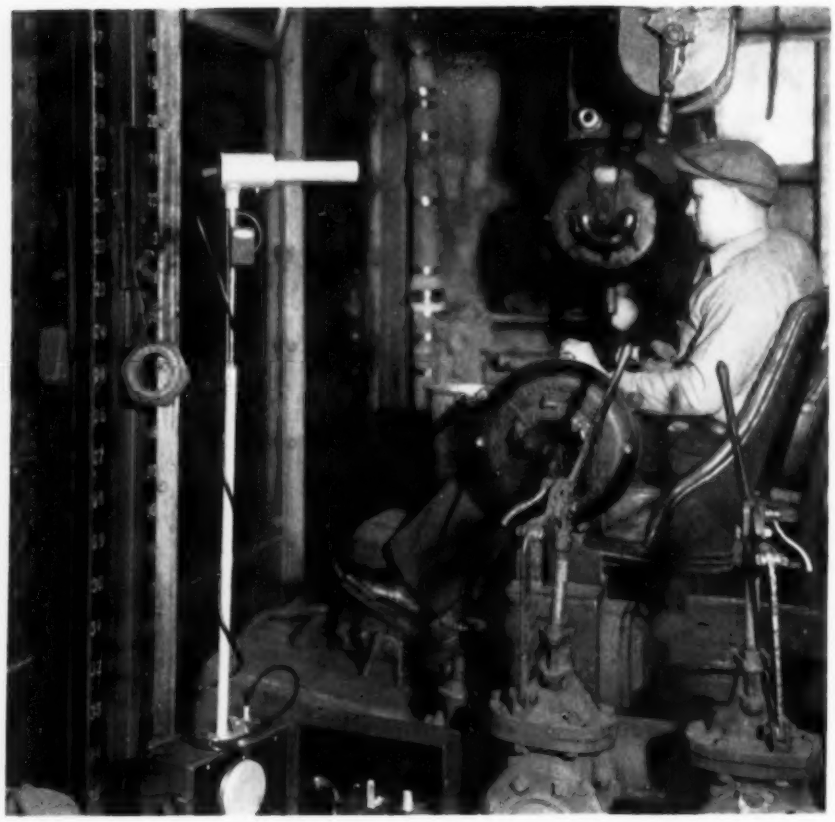
Air sampling in the merchant mills indicates that no hazardous exposure exists there. In scarfing no hazard exists unless a man is engaged over many hours of each day on Ledloy steels and the conditions are such that he gets in the drift of fume. Precautions could easily be taken by rotating men, distributing the work, or by an exhaust or other protective system.

In all, over 250 samples have been taken of the atmosphere in working spaces at Inland plants in determining where a health hazard might exist. At the point of addition of lead to the steel a hazard was found but this was promptly eliminated by the design and use of an efficient exhaust system.

Contamination of Outside Atmosphere

There are only two points in our manufacture at which lead fume is exhausted directly to the outside atmosphere. These are the discharge from the exhaust system at the openhearth pouring stands and the stack gases from openhearths melting Ledloy butts and scrap containing lead.

Concentration of lead due to discharge at these points has been estimated by two methods; *(a)* by determining the quantity of lead dis-



Sampling Air Breathed by the Roller in the Pulpit of a Blooming Mill. Sampling tube is at level of roller's head; electrostatic equipment for catching fume is only partly visible at lower left

charged and calculating the dilution in the surrounding atmosphere; *(b)* by direct sampling of the air at various locations, including particularly the direct drift of the gases discharged.

Calculations based upon a charge in a 100-ton furnace of which 12.5 tons is lead-bearing steel containing 0.25% Pb, assuming that all of the lead goes out as fine dust in the atmosphere during the 6-hr. melt-down period, and further assuming a threshold value of 3.0 mg. in 10 cu.m. of air, indicate that such a furnace could discharge into a block of air one mile cube continuously for 15,900 hr. or approximately 11 days before reaching an average concentration in such a hypothetical block of still air equal to the threshold value. Again, the records of the U. S. Weather Bureau show that the grand average wind velocity in the Chicago district for the past 23 years is 11.3 miles per hour. The air passing through a frame normal to the wind at this velocity is such that an opening 118 ft. square will dilute the stack gases to threshold value.

These are merely attempts to make comprehensible the approximate volumes of air required for dilution. All actual air samples taken out-of-doors have been within the threshold value.

The peak of contamination of the surrounding atmosphere during the 30 min. of heaviest discharge from the exhaust system at the openhearth pouring stands during the teeming of lead heats has been shown to be within safe limits by air sampling at varying distances from the stack in the direct drift of the smoke and fume. In order to get peak concentrations these samples were taken only during the 25 min. required to teem a lead heat. 250 ft. from the stack the air contained 1.74 mg. in 10 cu.m. 50 ft. further the figure had dropped to 0.42 mg., and 1100 ft. from the stack the lead had been diluted to 0.35 mg. Making one heat of lead-bearing steel a day, these concentrations would exist only in the direct drift of the smoke for approximately 3% of the time and the points of maximum concentration will be changed in accordance with shifting of the wind. Thus the average concentration at any given point is very low.

Contamination of Furnaces

To determine what health hazard might exist in cleaning, repairing and rebuilding openhearth furnaces, some sampling was done of the dust accumulated in passages of the regenerator chambers and flues of a furnace in which 955,200 lb. of Ledloy steel butts had been charged, distributed among 56 heats, none however exceeding 23,400 lb. of leaded steel in the heat. Results follow:

Furnace bottom (about 20 in. in front of the tap hole) at its lowest point; sample taken from surface: Nil.

Furnace banks at back, opposite No. 3 door at top of slag line: Nil.

Slag from bottom 6 in. of layer in east pocket (all slag samples at center of slag pocket): Nil.

Middle of the slag in east pocket: Nil.

Slag 4 in. below top of slag at end of campaign in east pocket: Nil.

Flue dust from top of checkers 3 ft. from bulkhead in west end: Nil.

Flue dust under checkers on floor of checker chamber 3 ft. in from start of flues at west end, 1 in. under surface of dust: 0.63%.

Flue dust under checkers on floor of checker chamber 3 ft. in from start of flues at west end, 8 in. under surface of dust and 2 in. from floor pavement: Nil.

Flue dust from center of flue at separation of tunnels for boiler and stack, 1 in. below surface of the dust: 2.38%.

Flue dust from center of flue at separation of tunnels for boiler and stack, 5 in. below surface of the dust and 2 in. from flue paving: 0.17%.

It is indicated that there is no retention of lead in furnace bottoms, banks or slag. The only accumulation found is from dust settled at certain points, probably where decreased velocity of gases or changes in direction favor the dropping of larger particles.

Since it is probable that only particles of relatively large size, aggregates of particles, or accretions could lodge against the sweep of the gases, it is probable that simple masks of approved type would provide sufficient protection to any workmen engaged in cleaning gas passages. The ability of various masks to filter out such dust will be checked, and air samples to determine whether a health hazard exists will be taken when another furnace is down into which lead butts have been charged.

No deleterious effects have been noted on any equipment. The one point about which question has been raised is its effect on furnace bottoms. Long before the manufacture of lead-bearing steels, stalactites or icicle-like formations of lead have been observed hanging from the under side of hearths. The lead probably comes from solder contaminating the steel scrap, including that in de-tinned scrap tin cans from tin recovery plants, and from bearing metals or other miscellaneous leaded material. Although the lead has obviously penetrated the bottom completely, no harmful results have been noted. From the analyses presented above it is apparent that lead does not remain in the refractories in contact with the metal bath or slag. Since it is not found in the slag either, it is probable that practically all of it goes out the stack. Lead boils at 2940° F. and litharge (PbO) boils at 2682° F. Likewise oxides of lead are at least partly reduced by iron. However, since litharge boils at temperatures reached in the openhearth furnace, we have some scientific evidence to corroborate the practical indication that lead is distilled off as lead oxide.

Handling Lead-Bearing Steel Scrap

It has been asked whether lead-bearing steel scrap should be segregated from other scrap during its collection or its preparation for remelting. Tests made at Inland show that the lead is completely removed in the furnace and does not change the properties of steel made. In one such test 23% of a total charge of 201,000 lb. was lead-bearing bloom butts. Analysis of stack gases showed the lead coming off during the melt-down period. A bath test at start of the lime boil showed 0.0039% Pb, indicating that the greater part of the lead was already removed. When the bottom was just clear the bath test showed 0.0034% Pb. A ladle test at the middle of the heat showed only 0.0013% Pb.

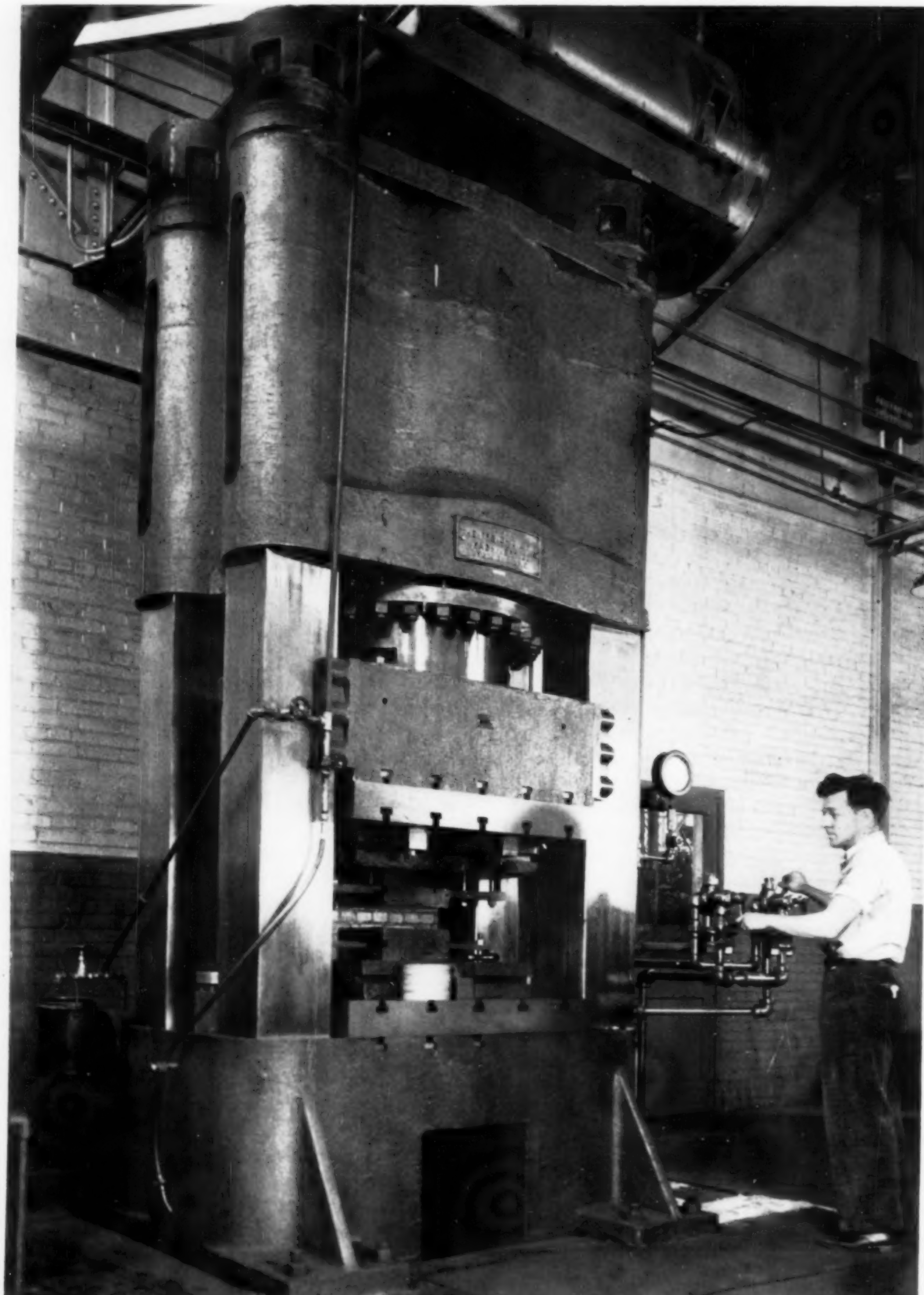
It can therefore be said with assurance that it is unnecessary to segregate lead-bearing scrap.

After having completed an initial survey of operations to make known any health hazard that may exist and after having reduced the lead concentrations to averages below the threshold value, it is still important to maintain an efficient control by periodic air sampling and by adequate medical supervision.

The method of control by air sampling has been illustrated. An additional factor is the possible build-up of lead in dust on structural members, crane runways and dirt floors. By studying the level of concentration when operations on leaded steels are *not* being performed, it is possible to detect any slow increase.

Control by medical supervision should include a physical examination at commencement of employment and subsequent routine examinations at intervals dependent upon the degree of exposure of the men. Such examinations include checking of the blood, and, in some cases, analysis of the urine and feces to determine whether abnormal lead concentration levels are present. Since it is already common practice to give employees in steel plants medical examinations and to have a system of plant inspection to determine and eliminate health hazards, no extensive changes or great expense are involved.

As a useful metal to man, lead is found in many industries. It has again proved its versatility by making possible better steels. Associated with lead there is *(Continued on page 518)*



Huge Hydraulic Presses, Like This One of 4,000,000-Lb. Capacity, Are Necessary for Making Metal Powder Compacts of Considerable Area. Courtesy E. S. Patch of Moraine Products Division, General Motors Corp.

Metal Powders: Characteristics and Products

By GREGORY J. COMSTOCK
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Handy and Harman, Bridgeport, Conn.

THE PRODUCTS OF POWDER METALlurgy must essentially consist of particles which are bonded together.

It has been demonstrated in practice that this bonding can either be complete or partial — and the products either dense or porous. Porosity is encouraged in the production of such things as bearings and bushings, but is discouraged in more instances, particularly in the production of tool materials and the ductile forms of the refractory metals.

Established products of powder manipulation demonstrate that particle bonding of two general types is possible. In one, particle-to-particle adhesion is developed (without melting) which closely resembles the intercrystalline bonding of cast materials. In the other type the bonding is effected by the cementing action of a constituent which is molten at some stage of the consolidating operations. Tungsten filaments are an example of the first, the hard cemented carbides of the second. In the October 1938 issue of METAL PROGRESS I expressed the opinion that in general the cementing of metallic particles by a molten bonding agent is the less versatile of these two methods of attachment.

Among the other *essentials of powder products* are that they consist of combinations of similar metallic particles, mixtures of particles of different metallic substances, or combinations of metallic and non-metallic particles. The familiar forms of tungsten, molybdenum and tantalum are examples of the bonding of similar metal particles. Elkonite, a proprietary metal powder product employed for welding electrodes, is an example of the bonding of the dissimilar metallic particles tungsten and copper. Silver-graphite contact material is a combination of metallic particles with non-metallic.

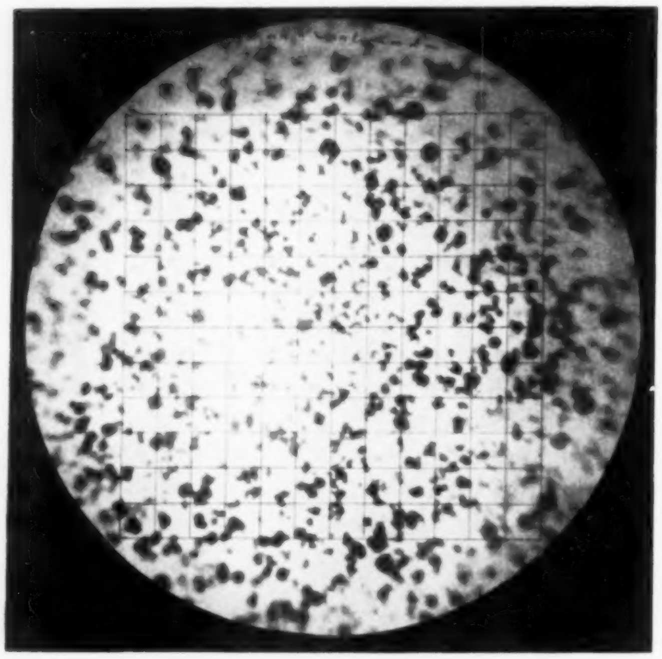
Powder products consisting of combinations of dissimilar particles can be classified into two further types. One type consists of powder combinations of metals which display an affinity for one another. The other type consists of powder combinations of metals which have no appreciable tendency to be miscible in any state. The copper-tin bearing may be regarded as an example of the first mentioned; silver-nickel, a ductile metal powder contact material, an illustration of the second.

Powder products originally composed of mixtures of metallic particles which have an affinity for one another may be manipulated so that the final product consists either of an alloy of the mixed powders, provided they are susceptible to diffusion alloying, or of the mutually bonded but practically unchanged original powder constituents. Blue gold alloys and "alnico" magnets are examples of diffusion alloying. Silver-copper, silver-nickel-cadmium, and other metal aggregates have been made to illustrate the other possible type of unions.

The physical characteristics of the product depend upon the final characteristics of the particles of which it is composed and the nature of the bond. The particle and the bond are therefore the two most fundamental considerations of this art which must be studied in any development of new products or the manipulations which are involved in their production.

The Particle — As has been said, it is demonstrably possible in some circumstances either to change the character of the original metallic particles by diffusion alloying, or to leave them relatively the same after the bonding has been effected. In the logical development of this art platinum particles were first manipulated to bond adjacent similar particles to produce a pure ductile metal. This represents the simplest form of powder combination and involves the least difficulty. The next development of the art was also applied to the production of essentially pure metals and was also effected by

Each Batch of Powder Used in Manufacture of Hard Carbide Tools Is Analyzed for Particle Size (a Frequency Curve Drawn) by Actual Count at 3000 Diameters of a Sample Dispersed on a Microscope Slide. This engraving, courtesy the Carboloy Co., is reproduced at 500 magnifications



bonding adjacent metallic particles without forming appreciable quantities of a molten constituent. It was, however, applied to much more difficult metals than the ductile, non-oxidizing, and very weldable platinum powder. The individual characteristics of tungsten, molybdenum, and tantalum were such that although the simplest form of powder product was desired, the technique was infinitely more complicated.

The next sequence involved a change to a mixture of different metallic particles, required alloying and the formation of unusual structural effects as well. The porous bearing with its continuity of porosity involved manipulations of considerable complexity even though they were applied to very much less recalcitrant metals.

The fourth combination to be established on a commercial scale not only involved the bonding of a metallic compound instead of a pure elemental particle but also a new type of bonding which was developed to meet the requirements thought necessary and desirable for the production of hard cemented carbides. The latest metal powder products give indications of being still more complex in their makeup. The "alnico" magnet, at least in the form of its first conception, involved diffusion alloying of its metallic powdered constituents with the formation of finally bonded particles which were different in their character and proximate composition from those of the original powder components.

It is obvious, therefore, that the particles which are bonded into metal powder products are progressively becoming more complex in character. One significant fact emerges from a study of them. None of the first established products of this art have involved the use of what might be called "alloy powders" unless the term can be broadened to include the hard metallic carbides. The latest products, however, involve such alloy particles, formed usually by diffusion alloying of the pure metallic components. This is in itself a fairly complicated operation either to conduct or to control. It would be eliminated if the alloys were available, *ready made*, in the form of finely divided powders. Bonding of such alloy particles would then revert to the simpler form which satisfactorily consolidates particles of pure metal.

Development of alloys in powder form must, therefore, be regarded as being one of the primary objectives of powder metallurgy. Any commercial process for making alloy powders must be fairly simple and economical; it also must be applicable to any melted combination of the metallics if it is to be utilized to its fullest extent. Should the alloy steels, the common non-ferrous alloys, and some of the more complex alloys which have demonstrated their suitability for special applications, become commercially available in powder form, a very real and important progressive advance in this art would be effected. If particles composed of combinations of the immiscible metals were included a further advance of considerable magnitude might be anticipated.

Commercial Powders — At the present time, however, the commercial metallic powders are chiefly the pure metals. Copper, nickel, cobalt, chromium, aluminum, magnesium, silicon, lead, zinc, iron, tungsten, molybdenum, tantalum, silver, gold, platinum, iridium, and doubtless others are available in powder form. Combinations of certain of these metallic elements are beginning to appear. Copper and lead or silver and molybdenum powders (prepared either by alternate or co-electrodeposition) are, as far as I can learn, the earliest of these bimetallic powders to be made in even limited production. The carbides of tungsten, titanium and tantalum as well as quite an impressive list of other hard

carbides, borides and nitrides can also be secured for powder manipulations. Some of the more brittle of the ferro-alloys lend themselves to mechanical division and are prepared as powders by that means.

Manufacturing Methods — Noel, Shaw and Gebert list the present method of powdering metals as follows:

1. Machining.
2. Milling (by ball, stamp or attrition mills).
3. Shotting molten metal in water or air.
4. Granulation by stirring molten metal while solidifying.
5. Atomizing or disintegrating by steam or compressed air.
6. Condensation of metal vapor.
7. Dissociation of carbonyls.
8. Reduction of oxide powders.
9. Chemical precipitation.
10. Electrolytic deposition.
11. Sintering (for the production of alloy powders in friable form).
12. Formation of an alloy followed by dissolving or otherwise removing one of the constituents.

Manufacture of metallic powders presents in itself an engrossing field for research and development. Its importance to the further growth of commercially applied powder metallurgy is self-evident. Obviously metal powder products must be made from metal powders. The availability of these powders, their composition, the size and conformation of the particles of which they are composed, and the cost of production in optimum form and size ranges, are questions asked when new metal powder products are considered. Due to the interest, enthusiasm and unflagging industry of a relatively few individuals this important phase has kept step with the commercial requirements. When specific powders have been demanded in quantity they have almost without exception been found to be available at a price which was not prohibitive. This represents no small achievement and a great deal of credit is, therefore, due to those who have been responsible.

It is interesting to note that almost without exception the later refinements and improvements of established metal powder products have resulted from a further study and development of the particles of which they are composed. The regulation of particle shape and density, and the careful modulation of particle sizes has been responsible for surprisingly great improvements. The cemented carbide tools are a good example, as their efficiency has been most notably increased by this means.

Views of "Infra-Sized" Graphite Particles, Magnified 175 Diameters. Size ranges are respectively 20 to 14 microns, 14 to 10 microns, and less than 10 microns. Courtesy Hugh Brown of W. S. Tyler Co.

Fretting Corrosion at Forced Fits

By G. A. Tomlinson
P. L. Thorpe
and H. J. Gough

Abstract of paper given March 3, 1939 before British Institution of Mechanical Engineers

Mutual corrosion at the contact surfaces of closely fitting machine components, when subject to vibration, has long been a source of considerable trouble. This corrosion must be distinguished from ordinary wear by the fact that it always occurs at contact surfaces which are for all practical purposes *fixed* in relation to each other. A common example is a ball race pressed on a shaft; the fitting surfaces, originally highly finished, are corroded and pitted in irregular patches, and usually a quantity of colored oxide debris is to be seen. The damaged areas on the two surfaces are generally almost identical, showing conclusively that the component has not moved during the process. Even force fits and shrink fits may be subject to this destructive action, as shown by the brownish slime often seen oozing from the junction.

Although the presence of oxidation products shows that chemical action accompanies fretting corrosion, the process nevertheless is almost certainly not one of corrosion as ordinarily understood. This is shown by the fact that there is no deterioration of the surfaces if the assemblage is at rest; vibration appears to be an essential factor in the process.

It is a peculiar feature that the susceptibility of the surfaces to attack appears to increase with the closeness of the fit and the degree of finish of the surfaces. It is frequently found on inspection that closely fitting surfaces of aircraft and automobile components are too much damaged to be reassembled, although in all other respects the parts may be quite serviceable. Furthermore, it is considered by some engineers that fatigue failures may be initiated by fretting effects, although there is no strong evidence either for or against this view.

In the first experimental work, carried out at the National Physical Laboratories, three rings with squared, lapped surfaces were slipped over a shaft and fixed to individual lever arms. The annular surfaces were squeezed together by calibrated springs and the center ring given a small vibratory motion by means of its arm linking into a Haigh alternating axial-stress machine, while the outer rings were held stationary. An optical system of very small mass attached to the rubbing surfaces magnified their motions so that 1×10^{-6} in. could be measured.

The results can best be appreciated from a description of a typical test with hardened steel specimens having clean, dry surfaces squeezed together under a normal stress of 6000 psi. If the measured relative movement of the surfaces in contact is plotted against the tangential force applied through the lever arms, a curve is plotted which looks like a stress-strain curve. That is to say, up to a point A, which in this case corresponds to a motion of about 20×10^{-6} in. and tangential force of 2500 lb., the curve is a straight line leading from the origin; at A occurs a sharp break toward the horizontal. From the origin to point A the motion is one of elastic distortion of material very close to the surface, and the conditions are reproducible. Above point A the relative movement becomes erratic; it is a combination of elastic displacement and pure slip, the latter occurring at the ends of the stress cycle where the stress for a short time exceeds the maximum force of friction.

A series of such tests shows quite definitely that slipping is a necessary condition for the occurrence of fretting corrosion. Without exception, in all the experiments with no slip the surfaces are practically unchanged, and when slip occurs the surfaces are always corroded to a greater or less extent, and generally have the characteristic oxide debris spread over them in irregular patches.

The experiments show that the presence of oil does not in any case prevent corrosion though it generally modifies the effect. The oil is never entirely forced out by the normal pressure. On examining the specimens afterwards, traces of oil in a dirty condition can be seen or wiped off the surfaces. It is probably all squeezed out, however, except for a very thin film which appears to be pierced at many places. There is little doubt that the metal breaks through the oil film, as the corrosion markings are permanent and cannot be wiped off, and the pattern on the one surface is always an exact facsimile of that on the other surface. No doubt the fretting action of the small alternating slip helps considerably in puncturing the film.

In general, the softer alloys show more tendency to seize and less tendency to produce corrosion debris than the hard steel. There is no difficulty in recognizing seized areas by their rough appearance and metallic luster.

Stainless steel proved particularly liable to seize; the slip indicator showed the surfaces to be continually sticking and breaking away, and this action could even be *(Continued on page 510)*

18-8:

Effect of Grain Size on Fatigue Strength

By H. HABART AND R. H. CAUGHEY
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FABRICATORS OF THE AUSTENITIC 18-8 alloys find that their products have structures which vary over a wide range with respect to grain size. It is conceded that very little control can be exercised over the grain size in 18-8 alloys throughout hot rolling and forging operations, because the material in cooling does not undergo an allotropic change. However, it seemed of considerable interest to know something of the specific effect of grain size, and to emphasize this condition two types of test bars were prepared, of which one was coarse grained and the other fine grained. Both were soft annealed and totally austenitic. The two types were tested for fatigue resistance in air (no liquid corrosion present) to determine whether the grain size of the material affected this particular property.

To eliminate differences due to chemistry, both types were prepared from a single 1.125-in. diameter bar having the following composition: Carbon 0.07%, manganese 0.46%, phosphorus 0.007%, sulphur 0.009%, silicon 0.55%, nickel 8.62% and chromium 18.80%.

After "soft annealing" (water quenching from 1920° F.) the bar was cold drawn to 0.675 in. diameter. The total reduction amounted to 64% and produced a cold-worked structure in which all the original austenite grains were thoroughly shattered. Auxiliary tests showed that this cold-worked 18-8 begins to recrystallize when heated at 1200° F., and that recrystallization is complete when heated at 1700° F. (The time at heat in these cases was 30 min.) It was also determined that the final grain size after recrystallization is dependent upon the time and temperature employed for a soft annealing treatment.

To make the two types of bars for the fatigue tests, the cold-drawn bar was cut into two parts. The fine-grained test bar was obtained by heating one part at 1920° F. for 15 min. followed by water quenching, which treatment produced a totally austenitic structure with a 5 to 7 grain size as shown by the left hand photomicrograph on the next page.

In order to obtain a test bar of uniformly coarse-grained steel it was necessary to employ an unusual procedure which consisted of heating the second part of the bar at 2100° F. for 2 hr. followed by water quenching. That treatment produced a totally austenitic structure with a uniform 0 to 1 grain size as shown by the right hand photomicrograph.

Effect of Grain Size on Tensile Strength and Hardness of 18-8

Properties	Fine Grain (5 to 7)	Coarse Grain (0 to 1)
Yield (0.5% stretch)	39,350	32,370
Ultimate	99,390	90,950
Elongation (2 in.)	71.6	76.3
Brinell number	166	156

Normally the grain size range of products made from 18-8 alloy is 1 to 7, so the grain sizes of the two bars are near the extremes of that range.

In addition to fatigue tests in air we determined the tensile properties and the hardness. In the tensile test, the yield point is taken as the stress necessary for 0.5% elongation. Results of the tensile and hardness tests are listed in the first table above. For the air fatigue tests,

10,000,000 cycles were used as the base for the endurance limits, and the results are shown in the table in this column, below.

Thus, the air endurance limit of the fine-grained type is 39,000 psi., which value is practically equivalent to the yield stress of 39,350. For the coarse-grained type, the endurance limit is 34,000 psi., which value is again quite close to the yield stress of 32,370. For both types, a distinctive feature is the abrupt decrease in the number of cycles required to produce failure at stresses 1000 psi. above the 10,000,000-cycle endurance limits.

Endurance (Rotating Beam) of Coarse-Grained and Fine-Grained 18-8

Type	Stress	Cycles	Remarks
Fine grain	± 42,000 psi.	29,000	Failed
	40,000	71,700	Failed
	39,000	10,259,100	No failure
	39,000	10,144,300	No failure
	38,000	10,013,500	No failure
Coarse grain	35,000	92,300	Failed
	34,000	10,015,400	No failure
	34,000	10,258,700	No failure
	33,000	10,004,000	No failure
	32,000	10,000,000	No failure

It is quite evident, from a comparison of the photomicrographs and the tensile test results, that the grain size of 18-8 is reflected in physical properties. Both types are totally austenitic. The fine-grained type has lower ductility, higher yield (stress at 0.5% elongation), ultimate strength and hardness than the coarse.

Because of the totally austenitic microstructure, both types must be considered to be soft annealed. The interesting feature of the fatigue tests is that the air endurance limits of both types are comparable to their respective yield stresses at 0.5% elongation. The difference of 5000 psi. between the endurance limits shows that the fine-grained steel has approximately 15% better fatigue resistance in air than the coarse-grained. Since the grain sizes represented in the two test bars are near the extremes of the grain size range normally obtained from commercial operations, it appears that the air fatigue resistance of soft annealed 18-8 products will vary within the 34,000 to 39,000-psi. range. Actually, a uniform grain size of 0 to 1 or coarser is not obtained commercially because it requires prolonged heating at very high temperatures. On that account, the 5000-psi. range should be reduced in commercial 18-8 to one which is small enough to warrant the assumption by fabricators that the air fatigue resistance of their products made of soft annealed austenitic 18-8 is not seriously affected by normal variations in grain size.

Microstructure, Enlarged 100 Diameters, of Samples Used in the Tests. Etched with oxalic acid. Grain sizes 5 to 7 and 0 to 1 respectively

Case Hardening Steels for Oil Production Tools

By HARRY W. McQUAID
Metallurgist
Republic Steel Corp.
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In discussing the metallurgical requirements of a given field of application it is usual to find that the designing engineer is convinced that his problems are more difficult of satisfactory metallurgical solution than those in other fields. The automotive engineer, for instance, is constantly limited by the requirements of interchangeability in mass production and a constant struggle for lower production costs. Tractors and trucks have to meet similar requirements in more severe service. Those engineers are constantly trying to produce parts which are so designed that they are good enough to perform satisfactorily in a highly competitive market without excessive field failures or expense. In the last analysis the choice is of a steel which produces a satisfactory part at the least final cost. Due to the relatively new development of metallography and the scientific study of the metallurgy of iron and steel, many of our designing engineers are lacking in a working knowledge of this important subject. (As a matter of fact many of our metallurgical friends are also lacking in a thorough groundwork in the fundamentals of machine design, so that a common ground is sometimes absent between the designer and the metallurgist.)

The designer of oil production equipment is faced by a problem of a somewhat different nature than those of the mass production fields. Because of the high initial investment, the extraordinarily high premium which successful performance gives, and the high penalty which failure of the equipment involves, he is constantly seeking for improved performance and longer life.

It is almost trite to state that resistance to abrasion and toughness are of primary importance to drilling equipment. Yet these two primary requirements are diametrically opposed. Wear resistance in a given steel depends primarily on the carbon content in the form of iron carbide, whereas toughness as ordinarily measured usually decreases with increase in iron carbide. The problem then becomes one of obtaining a combination of high wear resistance with satisfactory toughness.

Let us start out with the statement, sometimes forgotten by metallurgists, that carbon, rather than alloying elements, is the primary factor in producing *hardness* in steel. This is well illustrated by a chart on the next page, borrowed from an paper by Messrs. Burns, Moore and Archer. Note that the maximum hardness of alloy steels of moderate alloy content has the same value as that of the plain carbon steel of similar carbon content.

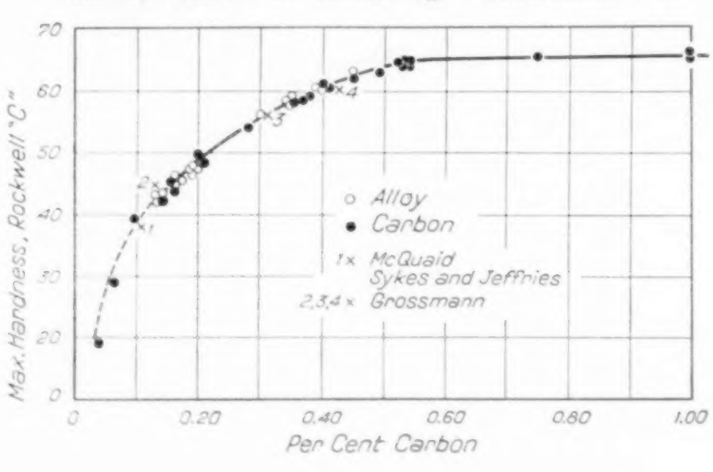
It is unnecessary to discuss the nature of hardness. It will be sufficient to say that maximum hardness on quenching is associated with a supersaturated solution of carbon in iron. This is a brittle microstructure called martensite. In the high carbon steels, such as in the surface of a casehardened steel, the hardness obtained on quenching is increased by the hard carbides *out* of solution. These hard carbides are a very important factor in obtaining maximum resistance to wear. The metallurgist's problem is to obtain the desired ductility or

Part of a paper "Some Factors Affecting the Selection of Steel for Oil Production Tools" read before the Western Metal Congress, 1938

toughness by sacrificing some of the hardness, and at the same time have available carbides in the best form to resist wear. This is done by tempering — reheating the hardened part to a temperature which will produce the desired properties.

Thus the fundamental requirement in obtaining resistance to wear is the presence of small particles of iron carbide at the contacting surface. (Sometimes in alloy steels there is some chromium, vanadium, molybdenum or manganese in the complex carbide.) In any event carbides are exceedingly hard but also very brittle so that as we build up the amount of carbide necessary to resist abrasion we at the same time decrease the ductility. Thus the designer, knowing that a given part must operate under high pressures against rock or sand, or against other hardened parts, specifies a high carbon or a carburized part, and it then becomes the problem for the metallurgist to try to obtain the necessary *toughness* by chemical analysis, special specification, and heat treatment.

Tests Show That Maximum Hardness Obtainable in Steel Is a Function of Its Carbon Content Rather Than of a Moderate Amount of Alloying Elements. After Burns, Moore and Archer, ⊕ Transactions, 1937



In this choice several paths are open. For a carburized part we can select from several analyses one steel which will have the highest properties in the core, and by carburizing increase the carbon content of the surface so that when properly treated the required resistance to abrasion is obtained at the surface. Or, we can select a special type of high carbon steel and by careful treatment obtain a fair degree of interior toughness combined with resistance to wear. Or we can combine either of the above with an overlay of tungsten carbide.

In any discussion of a casehardened part one usually hears that the combination of case and core gives a "hard, wear resisting surface combined with a tough, ductile core". As a matter of fact the toughness or ductility of the core really plays a very unimportant part in the performance. Contrary to the usual belief it is difficult to conceive of the core being subjected to any appreciable elongation without complete failure of the case.

For this reason it is believed we should concentrate attention on the properties of the hardened case, remembering that the most important property of the core is resistance to deformation under compressive stresses. Such tensile properties as elongation or reduction of area in the core or even the resistance to impact are of little value as a means for determining the properties of the finished part.

Therefore the casehardening steels are, in my opinion, best divided according to the strength and other properties of the *case*, after proper carburization and heat treatment.

There are a few commercial steels which seem to lie in a group having maximum case strength; their properties in the case are, generally speaking, commercially equivalent. This class includes the high chromium-nickel grade, such as the Krupp analysis and S.A.E. 3312, the high nickel steel S.A.E. 2515, the high nickel-molybdenum S.A.E. 4820, and the chromium-nickel-molybdenum grade and perhaps other combinations. They exhibit their best properties in the fine-grained type, double treated to produce a minimum of austenite — that is to say they should have a case which is 100% martensite. (Any austenite which may be retained after the quench is relatively soft as compared to martensite and means carbon retained in solution, and hence of reduced value for resistance to surface wear.) If there is more than enough carbon for the martensite and this excess carbon exists in the form of a network or boundary envelopes around martensitic grains the toughness is reduced greatly. Likewise austenite, which occupies a smaller volume than martensite and generally envelops the martensite, sets up considerable internal stress. It results that any appreciable amount of austenite results in a *decrease* in maximum tensile strength. Since austenite is directly related to excess carbon above the eutectoid (approximately 0.80% carbon) the steels mentioned

above attain maximum strength when the maximum carbon content is close to the eutectoid. In the fine-grained type, double treated, they will show a minimum case strength in tension of approximately 300,000 psi. The case strength of the coarse-grained type will be slightly lowered, and the toughness very much reduced. Treatments which tend to promote austenite reduce the strength rapidly, so these steels are rarely quenched from the carburizing temperatures but are given a double treatment.

These highly alloyed casehardening steels represent the maximum in case (and core) properties, but they also represent the maximum in first cost and cost of processing. They are used for such parts as cutters for rotary bits, heavily loaded gears, and slush pump parts where the return from the improved performance outweighs difficulties in processing and high costs. Their selection imposes considerable additional responsibility on the metallurgical department. They require special care in the making, rolling and forging to insure best results in heat treating and they must be very carefully annealed to machine reasonably well. Carburizing to a case free from excess (hypereutectoid) carbon is very difficult to do on a commercial scale, and requires gas carburizing equipment with all its special supervision. Double treatment to insure the desired core and case properties is much more difficult than with simpler steels which can be quenched under more advantageous conditions. All in all, parts made of these steels are relatively costly.

Specific Applications

We might now try to decide which steel in this group we would select for our cutter, gear, or pump shaft.

If a very careful study is made of *case* properties we will find that there is little choice, the normal variations in melting practice, carburizing practice and heat treatment being greater than variation in properties due to analysis. The same is true of the *core* properties where, in addition to the above variables, we have the carbon content to consider. High alloy steels of carburizing grade are very sensitive to carbon variation, so that the cheaper types in higher carbon may frequently show better core properties than the more expensive ones with low carbon content.

In the class under discussion the S.A.E. nickel-molybdenum 4820 is at present the most

Test Set-Up in Laboratory of Hughes Tool Co. to Study Action of Rotary Bit in Boring Through Various Rock Formations

widely used steel with a slight trend to the type having approximately 2% nickel, 0.60% chromium and 0.25% molybdenum (S.A.E. 4300). It is quite possible that the future may develop combinations of silicon, molybdenum, and chromium now not being used in this class.

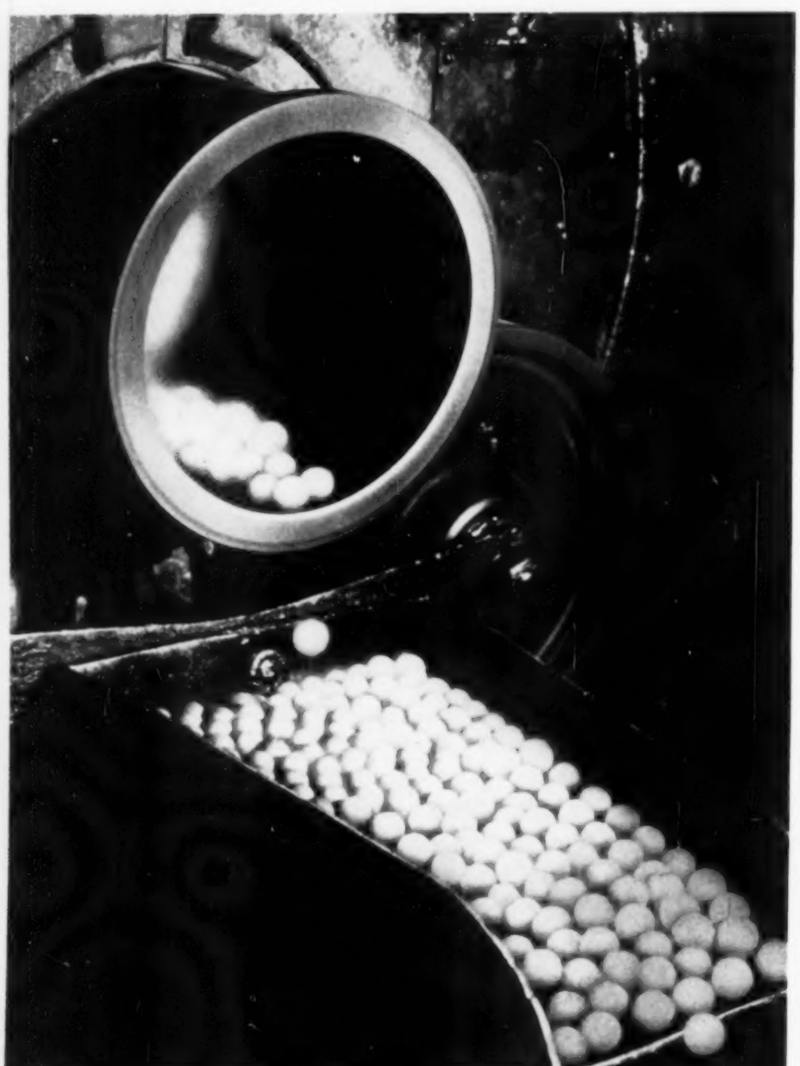
It will be noticed that the steels in this group all contain nickel. Nickel strengthens the steel not by forming hard carbides but by forming a nickel-iron alloy stronger than the iron without it. It is an extremely important addition where an increase in strength and toughness is a primary requisite. In order to improve the resistance of nickel steels to abrasion a carbide forming element, such as chromium or molybdenum, is usually added. When operations develop relatively high surface temperatures the addition of molybdenum seems to reduce the tendency to soften.

The 5% nickel steel and the high chromium-nickel steel (Krupp) were formerly very popular where the lower alloy grades gave trouble in severe service. The Krupp carburizing grade is high in first cost and difficult to process as compared to the lower alloy types.

It combines just about the maximum in case and core properties when double treated but is not so satisfactory when single treated. Its use in the oil industry is now confined to special roller bearings and a few other applications.

Steels of Wider Utility

The second group of carburized steels which can be used for practically all applications includes such steels as the low nickel-molybdenum (S.A.E. 4620); 1.25 nickel, 0.6 chromium (S.A.E. 3120); and the chromium steels, either straight (S.A.E. 5120), or with molybdenum (S.A.E. 4120), or with vanadium (S.A.E. 6120). These steels are not difficult to machine and when the proper attention is given to carbon content and grain characteristics they will exhibit properties which approach those of the higher alloyed steels. Since they tend to form less austenite on quenching, particularly in the chromium and chromium-vanadium grades, they can be single quenched and in the finer-grained type can be quenched directly from the carburizing box.



Heat Treating Balls for Bearings Within Cutter Bits. The excellent photographs used in this article were kindly furnished by Hughes Tool Co. of Houston, Texas

These steels are widely used in other industries and hence are easily obtainable. As a group they vary rather widely in price, more so in fact than their properties would indicate. It is of particular importance that the carburizing steels in this group be made to carefully controlled hardenability. Unless they are made in the fine-grained, shallow hardening type they will show poor fractures and relatively poor properties when quenched directly from the carburizing heat.

Most readers of this article will know what is meant by hardenability control and grain size. Practically it means that steels of the same chemical specification can be made to have widely different properties by changing the steel melting practice — that is to say, the hardenability and ductility can be varied in a given analysis by the steel maker.

Steels are specified as to the grain size after a standard carburizing test which outlines the eutectoid (pearlite) grains by excess carbide. Steels which exhibit little or no tendency for these boundary carbides to coalesce are called "normal", while those which show a decided tendency for the boundary carbides to coalesce are called "abnormal". For our purpose it is sufficient to state that the smaller the grain size and the more coalesced the carbide the shallower hardening a given analysis will be. Conversely the larger the grain (relatively) and the less the carbide coalescence the deeper the steel will harden. Generally, the fine grain will tend to coalesce while the coarse grain will not.

By making steels which will retain their fine grain above the carburizing temperature, work can be quenched directly from the carburizing temperature. This has resulted in a decided tendency to substitute this treatment for the more expensive reheating treatments. To the designer and user of oil production tools the so-called grain size specification has become of great importance. Fine-grained steels have so much better case and core properties that the lower alloyed steels have become more interesting than the higher alloyed ones.

The grain size specification has also resulted in a better control of distortion in quenching,

which is an important factor in the success or failure of many parts.

Another important result of the grain size specification has been to reduce the spread in properties which used to distinguish many of our analyses. This has resulted in a gradual simplification in specifications, and, while it made the selection of a given analysis more difficult, tended to accentuate the price difference. Thus we should find, for the general requirements of carburized parts for oil production equipment, a wide interest in the simpler, lower priced alloy steels made to carefully controlled hardenability requirements. Since the shallow hardening type of steels permit higher carbons for most purposes, the lower alloyed steels can be made to give surprisingly good properties in the finished part if this feature is remembered.

Alloy steel of some sort is almost universally used for parts of oil production equipment where a carburizing steel is required. The straight carbon grades in the fine-grained type, with manganese above 0.50%, will harden satisfactorily in water, but in a section of appreciable size they will not harden satisfactorily in oil. This means that they are subject to increased distortion as compared to the alloy steels, and where this is an important factor in performance they have been replaced. The carbon steels are mainly used in minor carburized parts, such as washers, although we still find them in some of the more important parts such as pump liners and some gears.

Cutter Teeth Are Covered With a Thin Layer of Hard Carbide Particles, as Described in Metal Progress *Last Month. This operator is using an atomic hydrogen flame for the purpose*

Nickel-Chromium Steel Most Popular

Reviewing the case hardened steels used in oil production tools, we find that for the most difficult applications the series which includes the high chromium-nickel, the 5% nickel, the 3½% nickel-molybdenum and the nickel-chromium-molybdenum is used. The 3½% nickel-molybdenum is probably the most popular grade due to its excellent case properties and also its ability to resist surface softening due to high friction in service. The properties of these steels in the finished part are dependent on steel making practice and they require close attention to the annealing and casehardening processes for satisfactory results.

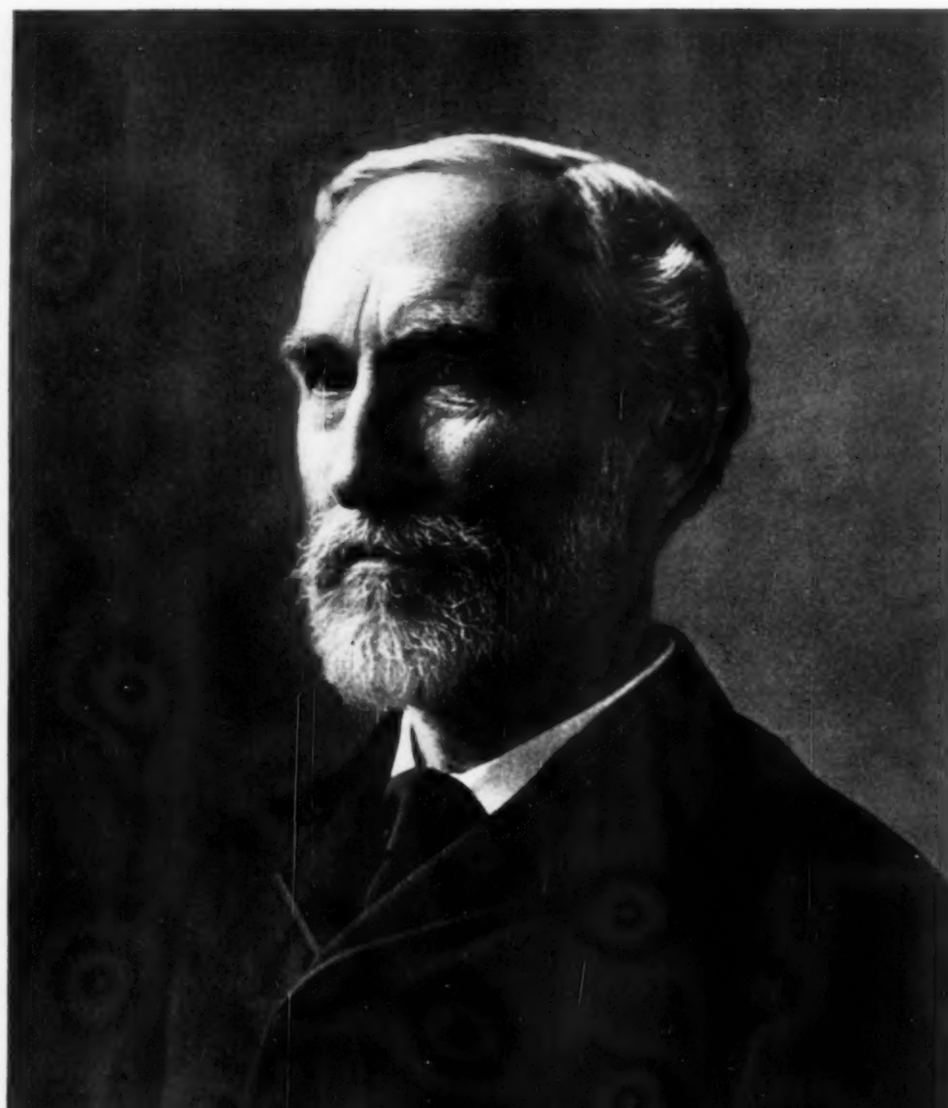
For other less exacting applications the choice is made from the lower alloy group which includes the S.A.E. 2315, S.A.E. 4620, S.A.E. 3120, S.A.E. 5120, S.A.E. 4120, and S.A.E. 6120. Due to hardenability control and generally improved understanding there is little to choose between them. At present the S.A.E. 3120 is probably the most popular with the S.A.E. 4620 running a close second.

The trend in this group in other industries seems to be to the lower priced grade such as the S.A.E. 5120, and it is probable that this trend will be felt in the oil production field. It must not be forgotten that these steels must be very carefully controlled as to hardenability and grain growth if they are to be satisfactory.

Centenary of a Great Scientist

J. Willard Gibbs

1839 — 1903



Copied from a heliogravure published by Ostwald in 1895

Biographical Note by John S. Marsh, Alloys of Iron Research, New York

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SOONER OR LATER, EVERY STUDENT OF metallography meets the "phase rule". The first encounter consists of memorizing some rigmarole about "degrees of freedom", "components", and "phases". In addition, he may learn that the rule was formulated by a man named Willard Gibbs. If the studies proceed, this name recurs, and he begins to perceive that Gibbs accomplished much in establishing a secure scientific foundation for the metallurgical and chemical industries, and that the phase rule is but one of many contributions.

Josiah Willard Gibbs was born in New Haven, Connecticut, on February 11, 1839 (so this is his centenary), and died there on April 28, 1903. Excepting summer holidays in the mountains, his only absence from the city of his birth was from 1866 to 1869, when he traveled in Europe and attended lectures in Paris, Berlin, and Heidelberg. This son of an eminent scholar inherited ability in the classics, for as an undergraduate he won prizes in Latin as well as in mathematics.

There is ample evidence, however, that Gibbs's interests extended to other fields, for subsequent to earning his doctorate in 1863, he tutored natural philosophy as well as Latin in Yale College. Further, as indication of a share of mechanical ingenuity, he obtained a patent in 1866 on a brake for railway cars; it would be interesting to know what brought this pre-Westinghouse problem to his mind. At about the same time, he invented a wholly practicable steam-engine governor, a working model of which is extant. A paper also exists, thought by some to be his doctoral dissertation, "On the Form of the Teeth of Wheels in Spur Gearing".

Such activity could hardly have foretold the gigantic things to come, but his ability and his lively interest in natural science must have been recognized, because in 1871 the 32-year-old scholar was appointed professor of mathematical physics at Yale. This marked the end of his active interest in applied mechanics, so far as is known. Two years later the first of the famous series on thermodynamic subjects appeared; publication of "On the Equilibrium of Heterogeneous Substances" extended from 1875 to 1878, and the part containing the phase rule was published in 1876.

With few exceptions the implications of the thermodynamical papers were not grasped by Gibbs's contemporaries, which was not strange, because he was years ahead of his time. For example, many of the deductions had to do with phenomena that were not observed experimentally until much later. This lack of understanding, however, did not prevent recognition, because he was elected a member of the National Academy in 1879 and was awarded the Rumford Medal in 1881. The Yale of his day suspected that he was an extraordinary person, but did not know exactly why he was extraordinary. Indeed, he received a long series of scientific and academic honors. His fame spread to even wider circles; for example, Henry Adams, the late historian, stated that: "Willard Gibbs stood on the same plane with the three or four greatest minds of his century. . . ." It has been suggested that Adams might well have said with Boltzmann, himself a notable physicist, that "in the history of physical science of the seventeenth, eighteenth and nineteenth centuries, Gibbs ranks with men like Newton, Lagrange, and Hamilton. . . ." It is curious that, although proposed several times, he has not been selected for the Hall of Fame.

Gibbs had extraordinary ability to discern the roots of matters; from assumptions reduced to the absolute minimum, he derived results of maximum generality. It is fortunate for metallurgy that this power was turned to thermodynamics. Best known to metallurgists, of course, is the phase rule; consequently, it may surprise the reader to learn that of some 400 pages on thermodynamic subjects, the phase rule as such occupies about one. In a way, this is roughly the correct ratio, because the rule is merely an unavoidable consequence of more important deductions. It must be remembered that when it first appeared, the only experimental data were on the simplest one-component systems and it is doubtful that even Gibbs could have forseen the tremendous value to industry of a correct means of qualitative treatment of systems of *any* number of components. Even if he had, however, it is unlikely that the section "On Coexistent Phases of Matter" would have undergone much expansion. The principles of our phase diagrams were clear to Gibbs, although he did not devote much time to describing these consequences of the general argument; this is attested by the fact that the

few geometric illustrations consist of the eutectic and transition-plane types of four-phase equilibria in ternary systems!

Gibbs's style of writing was highly condensed, but exceedingly precise. This makes it difficult for the reader at first, but later he comes to appreciate the absence of muddy definitions and ambiguous statements. Further, Gibbs never wrote or spoke of his investigations until all was complete down to the last detail. An example of his rigorous brevity is the definition of equilibrium: "For the equilibrium of any isolated system it is necessary and sufficient that, in all possible variations in the state of the system which do not alter its entropy, the variation of its energy shall either vanish or be positive." Expressed in mathematical notation this is $(\delta E)_S \geq 0$. These symbols and 40 words have since been expanded to many thousands to illustrate their full significance. Such explanations are certainly necessary, because the phase rule applies only to phases in equilibrium; to many persons able to make useful application of the phase rule the 40-word definition, in the ultimately brief form so useful to Gibbs, would be very inadequate.

Model of an Entropy-Energy-Volume Surface Constructed by Clerk Maxwell and Sent to Gibbs. (Courtesy of L. W. McKeehan)

The statement is sometimes made that Gibbs's thermodynamic papers were unappreciated until Ostwald's German translation became available, but this is untrue. Their worth was perceived at once by J. Clerk Maxwell in England and by J. D. van der Waals in Holland. The former was so impressed that he constructed a model of an energy-entropy-volume surface, a cast of which he sent to Gibbs. It is from a photograph of that casting that the accompanying cut was made. Van der Waals called the attention of Roozeboom to the papers; this was the beginning of the Dutch school which accomplished so much in developing phase diagrams in the form understandable to metallurgists and chemists. (In fact, the science of metallography might be said to have begun with Roozeboom's iron-carbon diagram.) Here again Gibbs's words have been amplified tremendously; "Heterogeneous Equilibria from the Standpoint of the Phase Rule", by Roozeboom and his associates, is longer than *all* of Gibb's thermodynamic papers, and there are many other "phase-rule" books by less noted authors.

As has been hinted, however, the phase rule is only a sample of the treasures to be found by diligent searchers in "On the Equilibrium of Heterogeneous Substances". One other example will suffice in this short note. Speaking of the principles formulated by himself (taught to all students of metallurgy), Le Chatelier stated: "Later, when I became acquainted with Gibbs's original memoir, I found that the laws which I had painfully established were only special cases of his general formula."

There is some evidence that Gibbs intended to return to thermodynamic subjects after an extended excursion into other fields, including higher algebra, vector analysis, astronomic calculations, and a monumental work on statistical mechanics, but this was unfortunately prevented. None will ever know how much future students would have been helped had he decided to use some of the homely, but apt, illustrations which had delighted his students, or how widely the boundaries of thermodynamics might have been extended.

For another view of the man who accomplished so much in the quiet halls of New Haven, it would be impossible to improve the words of Bumstead: "Unassuming in manner, genial and kindly in his intercourse with his fellow-men, never showing impatience or irritation, devoid of personal ambition of the baser sort or of the slightest desire to exalt himself, he went far toward realizing the ideal of the unselfish, Christian gentleman. In the minds of those who knew him, the greatness of his intellectual achievements will never overshadow the beauty and dignity of his life."

An Experimental Openhearth Furnace

By HAROLD K. WORK
Manager of Research & Development
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Jones & Laughlin Steel Corp.
Pittsburgh

RESEARCH IN ONE FORM OR ANOTHER has long been present in the steel industry although it is only recently that it has become customary to dignify it by that title. This research has either been carried on in separate laboratories or in the mills themselves. The separate laboratory, as our Corporation has found, furnishes a place where ideas of value to the industry are readily generated, but it is difficult to take such developments and put them directly into the mill. Attempts to do this result in a high percentage of failures. On the other hand, studies in the mill must usually be restricted to conditions which will produce a commercially salable product; otherwise the costs are excessive.

In the light of the above situation our Corporation, acting upon the suggestion of its general metallurgist, H. W. Graham, has attempted to bridge the gap between the laboratory and the mill in its research work by the use of equipment resembling the pilot plants so commonly used in the chemical industry.

As might naturally be expected, the program of the Research and Development Division is largely concerned with the making of steel. It is obvious that the proper place to study steel making problems is at a steel making furnace, but as has been indicated it is not convenient to conduct all such studies in large furnaces. For this reason, when it was decided in 1936 to provide a new laboratory building and facilities, it was planned to include an openhearth furnace, duplicating as far as possible the mill furnaces in construction and operation —but of laboratory size.

The term "laboratory size" is usually associated with test-tube dimensions. When applied to steel melting furnaces it brings to mind the induction furnace with a capacity of about 25 to 30 lb. A furnace of this type is commonly used in the typical research laboratory. However, the results obtained are not comparable with those obtained in mill equipment and their value is therefore considerably restricted.

Consequently it was decided that a small openhearth furnace was required for representative experimental work. Relatively few such furnaces had been constructed, and the available information on how to build one was very meager.

Other Small Openhearths—Examination of the literature revealed scattering references:

In 1891 the Metallurgical Department of the Sheffield Technical School was operating a 2500-lb. regenerative basic openhearth furnace, burning gas. Checkers were placed on top of the furnace, directly over the ports, to minimize heat losses, and the hearth in vertical section was a segment of a circle. The total length of the hearth was a little more than twice its width, but at the slag line the bath surface was nearly square. In 1903 a new openhearth of 5000-lb. capacity was built, in which the overhead location of the checkers was apparently abandoned. This furnace burned tar or gas from a producer.

An article in *Stahl und Eisen* in 1904 discussed the economies of ½-ton to 2-ton acid openhearths for foundry use. Over 100 of these were stated to have been built and successfully operated in the preceding 30 years in Germany, Austria, and other European countries, but no construction data were given in the article.

No further references were found until 1927 when a Bureau of Mines' publication mentioned a

Based on information presented to Openhearth Conference, A.I.M.E., Cleveland, April 28

200-lb. basic openhearth furnace built at its North Central Experiment Station. This furnace was also regenerative, with the checkers at each end. The hearth dimensions were 28 in. long by 11 in. wide with a maximum depth of 6 in. Gas was burned. Nothing was said about its operation other than that "the lining presented problems". In 1930 a second paper described a larger furnace of 1000-lb. capacity. This was a tilting furnace (the only example of a small tilting furnace found). The furnace body proper was cylindrical in shape, the bath at the slag line being about 3 ft. 2 in. wide, 5 ft. long, and a maximum of 10 in. deep. The checkers were placed underground, but it was necessary to fill the uptakes with checkers also to reach steel melting temperatures. Oil was burned.

In 1927 the Chrome Steel Works at Cartaret, N. J., built a one-ton regenerative acid-lined openhearth. The bath was 6 ft. 4 in. long at the slag line and 3 ft. wide, with a maximum depth of 10 in. The checkers were placed underground and oil was burned. This furnace was stated to have operated successfully for over 125 heats, none of which, however, was apparently under 0.20% carbon. In the next year a larger furnace of 5000-lb. capacity was constructed.

An article in *The Foundry* for May, 1935, described a 1000-lb. acid lined furnace, without giving the location or owner. This furnace was regenerative, with the checkers mounted directly above the ports, as at the University of Sheffield. The bath was 4 ft. by 1 ft. 6 in. by 4 in. deep at the slag line. Crank-case drainings were the fuel.

Plan of Experimental Furnace

Our experimental furnace was planned in the Research and Development Division and designed and constructed by the Pittsburgh Works Engineering Department of our Corporation. Before a drawing was made the various aspects of the problem were considered, and an attempt made to anticipate every difficulty which might arise.

The question of size was first decided. The information available concerning small openhearths previously built indicated that 1000 lb. was about the lower limit for a successful steel melting furnace. Below this size heat losses apparently became disproportionately large; it is also difficult to adjust the flame properly in a very small hearth. Furthermore, we desired to make rimming as well as killed heats in the furnace, and as it was believed (and since confirmed) that rimming would be difficult if not impossible in small ingot molds, it was decided to make the furnace large enough to supply at least a 1000-lb. ingot. A capacity of 1500 lb. was tentatively decided upon; this was, however, later increased 50%.

Hearth lines were next considered. In the small regenerative furnaces previously built the lines appear to be scaled down from larger furnaces, except for some lengthening and narrowing. This hearth distortion, made necessary because of the relatively greater length of flame in small furnaces, becomes more acute the smaller the furnace, and is a factor limiting the minimum size. (This becomes obvious from the drawing of our furnace, reproduced on the opposite page.)

The influence of the method of firing upon hearth lines is even more pronounced in small furnaces than in large ones. Scaling down of the ports and burners of a large furnace, no matter how successful, is no assurance of success in a small furnace. The logical procedure appeared to be to design burners capable of supplying the necessary heat with a short flame, then adjust the burner design, location, and hearth lines, one against the others, to the best overall balance. In our case this balance worked out to be an approximately circular hearth, fired by three burners specially designed by Prof. W. Trinks of Carnegie Institute of Technology. The dish-shaped hearth and roughly spherical interior space efficiently conserve the heat supplied, are easy to build and maintain, and convenient to work with in melting. The three short-flame burners provide efficient heating for the chosen shape of hearth.

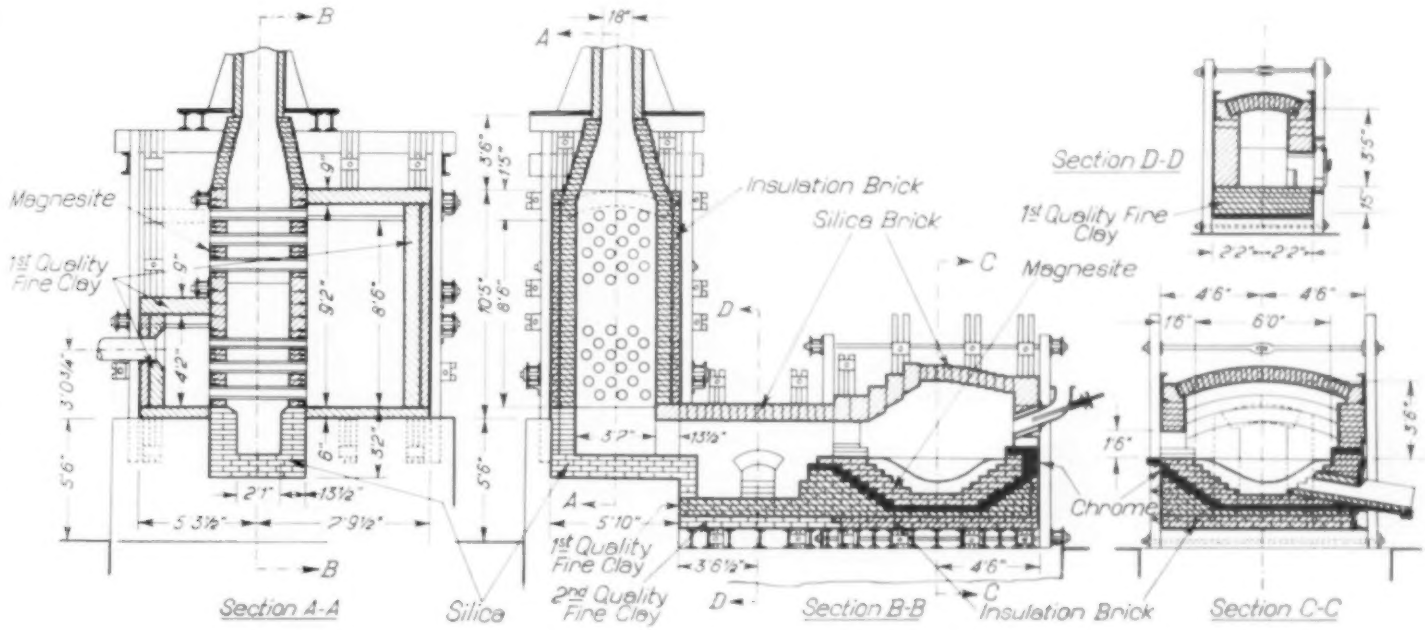
The next problem to be considered was that of preheating the air for the burners. The three-burner arrangement, which appeared by far the most efficient method of heating, was poorly adapted to the usual regenerative design, but well suited to a one-way fired furnace. Other disadvantages of the usual reversing regenerative firing, such as lack of full control over the air supplied, and irregularity of heating due to periodic reversals, appeared likely to be more detrimental in the operation of a small furnace than of a large one. The size of the checkers computed to be necessary was found to be quite large compared to the size of the furnace itself.

For these reasons it was finally decided to abandon conventional design, do away with the checkers, and build a one-way fired furnace equipped with a recuperator made of carborundum tubes, which have a heat conductivity much higher than brick and transfer heat with considerably higher efficiency.

The plan finally adopted permits efficient and uniform heating of the bath by means of three short-flame burners, a high degree of heat conservation because of the roughly spherical hearth space and compact furnace shape, easy construction, maintenance, and operation, full control over both air and gas supplied to the burners, and efficient preheating of the air in the recuperator.

Lines — The lines and dimensions of the furnace may be seen from the accompanying drawing. The bath at the slag line is square, about 4.5 ft. on a side, with a dish-shaped bottom having a maximum depth of 12 in. (In the bath to the recuperator where it would attack the carborundum tubes. A clean-out door 18 in. square is provided.

The Recuperator itself consists of two horizontal banks of 18 carborundum tubes each, equipped with corebusters. The tubes are 6 in. outside diameter with a 1-in. wall, and are 4 ft. 4 in. long. The whole recuperator structure is elevated on a solid concrete base sufficiently to raise the lowest row of tubes several inches above the top of the slag pocket, as a further precaution to avoid attack by iron oxide carried out of the hearth. The exhaust gases flow upward around the outside of the

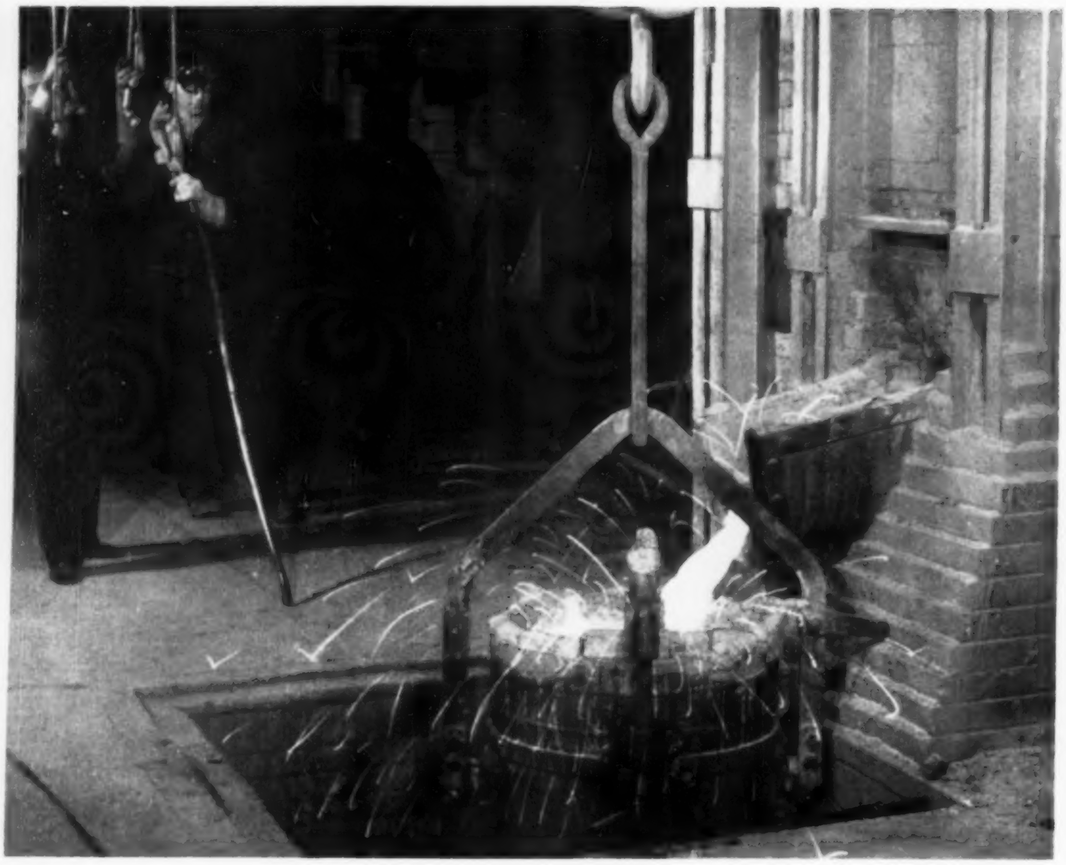


Furnace for Experimental Steel Making Has a Spherical Hearth and a Large Slag Pocket Between Its Exhaust Port and the Recuperator for Preheating the Combustion Air

operation the bath depth is usually several inches less.) The bottom is magnesite, fused in to a minimum depth of 6 in. on 6 in. of magnesite brick. The silica brick roof is arched from front to back, on a 4-ft. radius, over a 6 ft. 9 in. span. The maximum height of the arch over the bottom is 4 ft. 5 in. The tap hole is 6 in. in diameter, and the charging door 18 in. square. The furnace as actually constructed has been found large enough to accommodate a 2700-lb. heat.

Slag Pocket — Between the exhaust port (which is 25 in. wide by 20 in. high) and the recuperator is a slag pocket of considerable size, being 6 ft. 9 in. long and 21 in. below the bottom of the exhaust port. This sizable pocket was interposed between furnace and recuperator to prevent iron oxide from being carried over from tubes and escape through an 18-in. stack. Air is drawn into the front end of the upper bank of tubes, through a chamber in the back, and out of the lower bank of tubes in the opposite direction by a fan driven by a 5-hp. variable speed motor. This air, which in normal operation is heated to a temperature of about 1200° F., is conducted through a well insulated pipe, 12½ in. outside diameter, to a cross header above three burners, which are supplied by separate 7-in. inside diameter pipes, equipped with valves.

Burners — The three burners, which were especially designed to provide the short flame necessary in such a small furnace, are cast with a 7-in. diameter air chamber and fitted with a 1¼-in. gas pipe, and enter the end wall of the furnace with a slope of one in three. The gas



Tapping a Heat of Steel Into a Well-Preheated Ladle

A total of 3550 lb. of magnesite was required to build the bottom up to a thickness of 6 in. in front of the tap hole. Since the furnace has been in operation, magnesite has been used, as it has been required, for patching purposes.

Furnace Charge — The furnace is charged by hand; a typical charge consists of 50% cold pig and 10% stone. In order to have complete information regarding the raw materials used, the balance of the heat (scrap) consists of billets from heats of open-hearth or bessemer steel, identified by heat numbers. Approximately 2½ hr. are required to melt down the charge prior to working the heat. The usual duration of the working period is about 1½ hr. Slag tests are taken for chemical analysis at the proper intervals to determine the correct additions to make.

pipe may be adjusted axially within the air chamber. The fuel, natural gas, is supplied to the burners through 1¼-in. flexible tubing from a 4-in. header. Each gas line is fitted with its own plug valve.

Construction — The furnace is solidly constructed on a poured concrete foundation, the furnace proper and slag pocket being raised above the concrete on 9-in. I-beams. Buckstays are paired 6-in. I-beams, pulled up with four tie rods each way, top and bottom. The recuperator is similarly built. The bottom of the furnace is insulated by two courses and the front and sides by one course of insulating brick; the recuperator is insulated all over with one course of insulating brick. All side walls are three courses thick or more. The fan and air lines are supported by an elevated structural framework, so as to be entirely independent of the furnace structure itself.

Furnace Operation

Bottom Making — Four days were required to burn in the bottom. This was built up by fusing in successive rounds of Washington magnesite mixed with 16% ground basic slag.

Rates of reaction in this small furnace are such that the removal of metalloids proceeds at a somewhat faster rate than in a large furnace. This is due to the fact that the bath is relatively shallow, which increases the ratio between the area of the slag-metal interface and the volume of the metal bath.

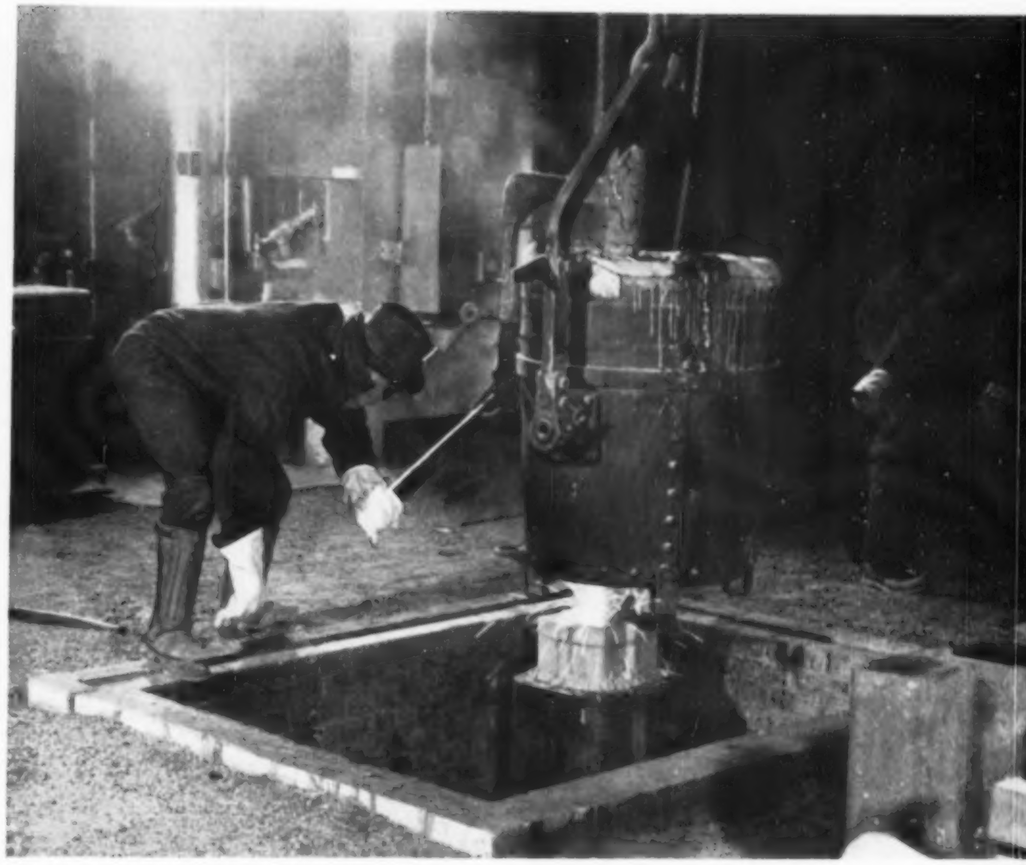
During the first campaign no sulphur or phosphorus trouble was encountered. However, this could be expected when using natural gas, good scrap, and a relatively high slag V-ratio.

As rimmed, semi-killed, and fully killed steels are made, deoxidation practice is varied to meet the requirements. It is the practice to deoxidize in the furnace whenever possible. In addition to the usual advantages obtained from this practice, deoxidation in the furnace is especially desirable for small heats since ladle additions have a decided chilling effect.

To insure a fast tap, which is essential to prevent large ladle skulls and pouring difficulties, a 6-in. diameter tap hole is used and closed with raw dolomite, and faced off with double burned dolomite. If the hole is properly closed, it is seldom necessary to use oxygen during tap-

ping. The ladle is also heated to a red color with a gas burner just prior to tapping.

Teeming the Heat — Since these small heats lose their temperature very rapidly and there is not sufficient ferrostatic head in the ladle to produce any cutting action on the steel which may freeze in the nozzle, it was found necessary to use 1½-in. to 2-in. nozzles. A clay plug is rammed up against a wad of paper placed in the nozzle to prevent any leaking prior to opening up the first time. Ingots of the following sizes are poured: 7x29x42-in. slabs of rimming steel for strip and tin plate; 11x11x39-in. killed steel in big end up molds with hot top for forging billets and tubular products (rimming and semi-killed steels are also poured in this size); and 6x6x24-in. open top ingots in killed or semi-killed steel for preliminary heats to be rolled in the small laboratory mill into bar sizes suitable for testing.



Teeming Killed Steel Into a 1100-Lb. Ingot Mold With Hot Top

The surface conditions of the ingots are, with the exception of the 6x6-in. ingots, generally as good or better than the usual run of production ingots.

Instrumentation — At present the furnace is manually controlled; however, equipment is provided for indicating and recording such information as roof temperature, temperature of air from recuperator, gas flow, air flow, and furnace pressure. Installation of equipment for fully automatic control — including air-fuel ratio, roof temperature, and furnace pressure — is being considered.

Operators — The furnace crew includes two metallurgists, one of these acting as melter foreman; the remainder are melters and first helpers from our openhearth shop. It is felt that this arrangement gives a good balance of technical and practical talent.

Recuperator Performance and Refractories — The recuperator installation has operated satisfactorily, and some very interesting data are being obtained concerning the advisability of using such a system in larger installations. This furnace also furnishes a possibility for studying refractories under conditions approaching mill service, and our plans include such studies.

Steel Quality — Before attempting any development or purely experimental work with this furnace, it was decided to make a series of heats for comparison purposes similar to a number of grades commonly produced in our openhearth shops. The results obtained from these heats indicated definitely that the physical properties of steels made in this small furnace were comparable, in general, with those produced in our mill furnaces. Now that this fact is established, it is possible to proceed confidently with our development work on steel making, knowing that the results obtained in the laboratory can be applied to production.

Acknowledgments

The authors wish to thank their many associates who have made this experimental openhearth possible, and particularly H. W. Graham, general metallurgist of Jones & Laughlin Steel Corp., whose vision was responsible for its installation.

The World's Fair in New York Contains so Many Bizarre Uses of Metal That it Presents a Perfect Excuse for Inspection by a Metallurgist

Critical Points

DIARY OF AN EDITOR

APRIL 1 — Read with much avidity an article in an English metallurgical journal about the production of what it called "stable" stainless steel. The well-known causes of intergranular corrosion and various commercial methods to form a stabilized microstructure or to fix the carbon in insoluble particles were admirably reviewed at considerable length. A simplified solution — the making of 18-8 almost carbon free — was by contrast pictured as being quite desirable, and the announcement that it was being done commercially and fulfilling expectations was called "an achievement of great importance". *But*, no word of *how* this metallurgical feat has been achieved. April fool!

"Stable" Stainless Steel

April 3 — As an afterthought, it came to mind that the problems of general corrosion and intergranular corrosion of 18-8 stainless steel are far better understood than the problems of pitting corrosion. In the extensive researches financed by the Chemical Foundation (and reported very briefly in the March issue) only two samples did not pit. One was a commercial 18-8 after vacuum annealing, and the other a very pure alloy melted under nitrogen, and containing considerable nitrogen. Both had as a common characteristic a single-phase structure of austenite.

One might therefore be tempted to think that perhaps a single-phase austenitic microstructure is more resistant to pitting (in the absence of any other contributing factor, as it doubtless is to general corrosion), were it not for the fact that 2 to 4% molybdenum added to 18-8 or 20-10 vastly increases the resistance to pit corrosion, yet this metal promotes a two-phase microstructure of delta and gamma iron.

Pitting Still an Unsolved Problem

RUSSELL FRANKS of Union Carbide & Carbon Research Laboratories writes that this still makes sense, for he has found that a moderate amount of molybdenum increases the resistance to pitting of either a 30% chromium-iron (wholly of alpha — or delta — iron) or a 20% chromium, 20% nickel alloy (wholly austenitic, of gamma iron). Consequently in an 18-8 with enough molybdenum so a little delta iron appears with the gamma austenite, the specific improvement in corrosion resistance of each phase due to molybdenum far more than counteracts whatever indirect harm there may be in promoting two-phase structure and a likelihood of electrolytic effects.

Purity of the two alloys quoted at the outset is probably not the controlling cause. Dr. KRIVOBOK, in his work preparatory to the Campbell Memorial Lecture (1934) made some very pure alloys. He tells me that he recently tested them, and they "pinholed". In fact, the sum of his very extensive information on the manufacture and use of stainless 18% chromium, 8% nickel alloys is about this:

"Some pit and some don't!"

April 6 — A review of a recent publication indicates that "hardenability" of steel has definitely emerged from the hazy uncertainty of "body". In fact, several methods of measuring it are current; eventually one method will be selected and standardized, but meanwhile there is a difficulty concerning names. It is more than an editor's worry, for metallurgists in Plant A and Plant B are comparing the hardenability of steels from Mill C and Mill D, and a common understanding of names of the test method is desirable. Aside from the "P-F" test for toolsteels suggested by Past-President SHEPHERD about five years ago where the hardness penetration and fracture grain size are compared after four standard quenches, and the fundamental determination of a critical cooling rate (which appeals more to researchers

Names for Hardenability Tests . . . .

than to practitioners), there seem to be three methods for rating hardenability now in use by American metallurgists:

1. The oldest, and rather obvious, determination of a size of bar or rod that will harden to the center during a standardized quench.

2. The scheme proposed by JOMINY and BOEGEHOLD of directing a water spray against the end of a hot 1-in. bar, measuring hardness down the bar, and grading the steel by the distance where the hardness number exceeds a figure selected with the application in mind, or by comparison of equivalent cooling rates, establishing the hardening response in varying sections.

3. Quenching by total immersion and measuring the hardness variation, edge to center, on a smoothed cross-section; more particularly the scheme recently suggested by BURNS, MOORE and ARCHER of denoting the hardenability by the area under a curve of Rockwell C numbers plotted against distance from center. (This is the same thing as the *average* hardness if, as suggested by them, a 1-in. bar is used.) Rather more information is given by noting the surface, average and center hardness — the so-called "S-A-C" rating.

Prior to any attempts at desirable standardization, and even before we know whether time at heat *before* quenching makes any difference, it may be too early to attempt to affix *names* to these tests. Perhaps eventually they will be described by the name of the man who suggested them, or devised the modification eventually standardized. For the present we note that they belong to two main groups, one of which studies the variation in lengthwise hardness, and the other the variation in crosswise hardness. If you like words with a more scientific sound, this distinction might be expressed as "lineal hardness" and "diametral hardness". Perhaps a more acceptable distinction should include some hint as to the method of test; lengthwise hardness could then be "end-quench hardness"; crosswise hardness is determined after total immersion.

What do you think?

April 10 — Word has filtered through that a certain gentleman who demonstrated his ability as a tool hardener in the Detroit region some years ago is again working the Central West. He studiously avoids talking applied science with the metallurgist, but usually approaches the production manager or superintendent of the machine shop, tells them of the wonderful improvements in tool life he made in a short time in Plant X, and convinces them he can do the same thing in this one — of course, for an appropriate fee. The man really knows tool design, treatment and use, and it is no trick at all for him to go into any shop operating by tradition and correct some things that are obviously wrong, with corresponding salutary effect. Lacking continuous technical control — as is frequently the case in shops where the tool hardening is done by the tool room or manufacturing division — it will unfortunately be only a short time until such operations revert to their original sloppy condition. In one well-managed plant the metallurgist made no objection to these useless ministrations, feeling that it would cost more than the fee to incur the suspicion of his elderly colleagues that he might be a bull-headed and high-browed scientist.

Metallurgists on the Spot

April 17 — GORDON WILLIAMS of Cleveland Tractor Co., mistakenly assuming that the data file which the Editor cultivates to a size which threatens to crowd him out of his office must contain an answer to anything, asked: "Where did the word 'pseudo-martensite' come from and what does it mean?" The August 1935 issue of METAL PROGRESS devoted to the nature and names of the constitutents of steel failed to mention it, and an hour's search through clippings in the drawer labeled, somewhat inclusively, "Transformation of Austenite; $Fe_3C \rightleftarrows 3Fe + C$" failed to find one recorded usage of the word. So a phone call to Pittsburgh brought the surmise immediately from Past President EDGAR BAIN that it was probably invented in the Union Carbide and Carbon Research laboratories about 15 years ago, for it was certainly used in discussions there among GUS KINZEL, JOE VILELLA and himself (and later by WALTER CRAFTS in his publications) to denote a structure frequently found in mildly quenched alloy steels of high hardenability; it etched to a needle-like appearance yet was softer than real martensite, say on the order of Rockwell C-45 instead of C-60. In the fullness of their ignorance it was also sometimes called "low carbon martensite".

What Is Pseudo-Martensite?

Its true position as an intermediate transformation constituent was demonstrated during

the investigations begun by Edmund Davenport and Edgar Bain at U. S. Steel Corp. Research Laboratory on the transformation of austenite at constant subcritical temperature, where it appeared as the somewhat feathery, acicular constituent in carbon steels transformed between 900 and 300° F., having correspondingly increasing hardness numbers from C-42 to C-60. Since this acicular product of transformation, different from martensite, has been dubbed "bainite" by some, the answer to Gordon Williams is: "Pseudo-martensite is bainite."

Maybe you will want to know, also.

April 20 — Worried on this day of Adolf Hitler's birth as to the outcome of the saber rattling, diplomatic maneuvering, and billingsgate which issues from the chancelleries of our so-called civilized nations. Mused, pessimistically, that man's memory is so very short and a new ignorant crop comes along every 20 years so history can repeat itself, so the chances seem to be for a horrible war, made universally devastating by the discoveries of scientists and their applications by engineers. Or have we engineers already made war so horrible to any people that to contemplate it is to reject it as being the worst of all evils? Or has mankind still to fight itself into such ruin and savagery that it will be glad to forget what it knows of science and industry? In this vein Sir Richard Gregory in a recent lecture in Washington in honor of Elihu Root said: "Science cannot be divorced from ethics, or rightly absolve itself from the human responsibilities in the application of its discoveries to destructive purposes in war, or economic disturbances in times of peace. Men of science cannot stand aside from the social and political questions involved in the structure which has been built from the materials provided by them, and which their discoveries may be used to destroy."

Pessimistic Interlude

For "science" also read "engineering".

April 24 — Impersonated Clifton Fadiman and imitated his radio program "Information Please" in still another experiment in the modernization of technical sessions, this time for the Cleveland Chapter. Several local experts (and I really mean experts) sat in front and answered questions about the selection of metals for particular services, mailed from the membership or asked by the audience. Adrian Weiss of Superior Die Casting Co. proved to be our John Kieran in his breadth of information about metals nonferrous. On the competition between die castings and plastic moldings he first pointed out the immense variety of the latter and for simplicity subdivided them into two classes, "thermal setting" which are solids compacted in a hot mold and held there until they set, and "thermo-plastic" which, like die castings, are melted and then squirted into molds.

Die Castings vs. Plastic Moldings

As to size, Weiss said that die castings have reached about 4 ft. long by 2 ft. wide, considerably larger than any thermal setting plastic moldings known to him (such as scale housings and radio cases), and much larger than thermoplastic castings such as steering wheel rims, the projected areas of which are comparatively small. Dimensional accuracy is on the same order and depends on the die and machine adjustments. Plastics are, however, of a much lower order of strength, having only about 8000 psi. tensile strength whereas magnesium die castings will run up to 30,000, aluminum 35,000 and zinc to 45,000 psi., depending on analysis and manufacturing technique. Impact strength of die castings is also considerably higher.

From a production standpoint, speed is essential, and here the die casting also has a great advantage. Largest die castings can be made one a minute, and 300 operations an hour are easily achieved on 1/4-lb. castings. Contrasted with this, thermal setting plastics require from 3 to 15 min. in the mold to cure. Injection molding of thermo-plastics is limited by the rate at which the raw material can be melted; on machines known to Weiss this is about 5 oz. per min. before charring commences.

Contributors

With a degree of Sc.B. (Met.) from Massachusetts Institute of Technology in 1922 and a D.Sc. from University of Nancy, France, in 1925, **Edwin Dudley Martin** has also studied at Cornell, Boston University, and Ecole Supérieure de la Metallurgie and de l'Industrie des Mines, France. As research chemist and metallurgical engineer for New Jersey Zinc Co., he made a survey of the zinc industry in Europe. In 1926 he switched to more commercial activities as assistant to the president, Edison Portland Cement Co. From 1929 to 1935 he was vice-president and general manager of Emark Battery Corp., and in 1934 was made vice-president of the parent company, Thomas A. Edison, Inc. In 1937 he made the jump back into the field of his original choice — the steel industry — as development engineer for Inland Steel Co. He is now assistant chief metallurgist in charge of development and research.

R. H. Caughey and **H. Habart** have both been with National Tube Co. since they received their respective degrees — Caughey a B.S. in metallurgy from Pennsylvania State College in 1935, and Habart a B.S. from Case in 1925 and M.S. from University of Alabama in 1926. Both are in the metallurgy department at the Ellwood Works.

Columbia University graduated **Harold Knowlton Work** (a down-easter born in Hartford, Conn.) with degrees of A.B. and Ch.E. in 1925. Securing a research fellowship at Mellon Institute of Industrial Research, he simultaneously continued his studies at University of Pittsburgh, receiving his Ph.D. in 1929. The next seven years were spent with Aluminum Co. of America as division head in the research laboratory and chemical engineer in the jobbing division. In 1936 he joined Jones & Laughlin Steel Corp. as manager of the Research and Development Department.

Co-author of the article on the small open-hearth is **Maurice H. Banta,** associated with Dr. Work as a division head in the research and development division. Born in Elwood, Ind., he has been with Jones & Laughlin since his graduation from Purdue University in 1930 with a B.S. in chemical engineering. For the first seven years he worked at the Aliquippa Works metallurgical department before being transferred to the Research and Development Department.

Although **Gregory Jamieson Comstock** was born in Cleveland, his early education was obtained in the public schools of Edgewood, Pa., and at Phillips Andover Academy. Following graduation in 1917 from Sheffield Scientific School he served in the U.S. Army for 2½ yr., whereby, in his own words, he "assisted some 80,000 horses and mules in their efforts to reach France to make the world safe for democracy". After the War he was employed successively as metallurgist with the American Hardware Corp., metallurgist and manager of experimental factory for the International Silver Co., Director of Research with Firth-Sterling Steel Co., and more recently as consultant in powder metallurgy and manager of Metal Powder Products Division for Handy and Harman, the well known firm of silver merchants. His recent interests have been in the development and production of hard cemented carbides and contact materials.

Gregory J. Comstock

Edwin D. Martin

Harold K. Work

Maurice H. Banta

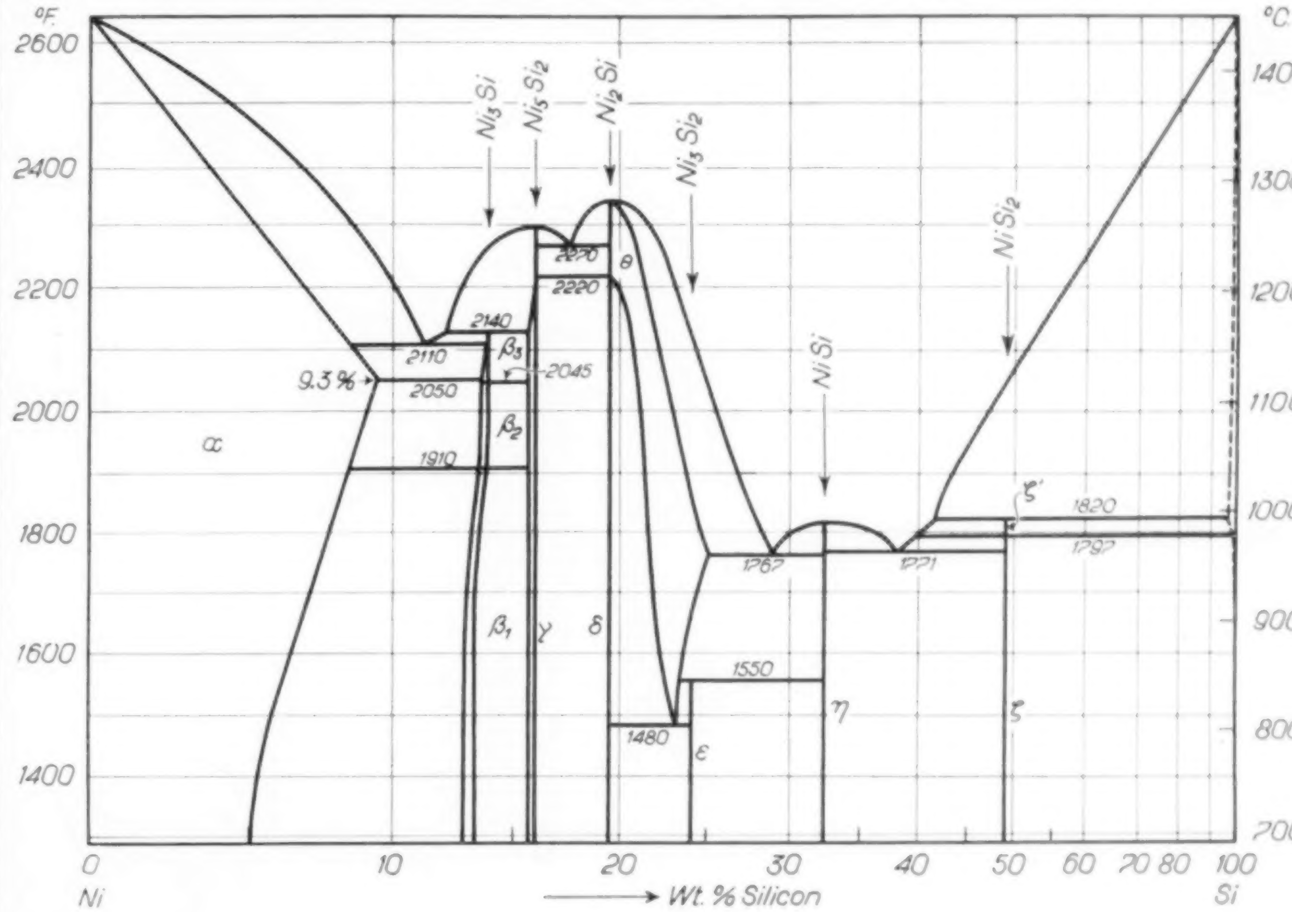
R. H. Caughey

METAL PROGRESS MAY, 1939; PAGE 489

The Nickel-Silicon System

By A. Osawa and M. Okamoto

Science Reports of the Tohoku Imperial University, Vol. 27, No. 3, January 1939, Page 326



Summary of the Results of X-Ray Investigations							
Phase	Formula	Weight % Si	Crystal Class and Lattice Constant in Angstrom Units		Atoms in Unit Cell	Micro-structure	Note
α		Less than 5	Face centered cubic	$a = 3.516_9$ to 3.510_0	4	Homogeneous	Lattice constant decreases linearly
β_1	Ni_3Si	13.0	Face centered cubic	$a = 3.496_9$	4	Homogeneous	Superstructure of the $AuCu_3$ type
γ	Ni_5Si_2	16.0	Orthohexagonal	$a = 13.28_9$, $b = 7.672_1$, $c = 9.751_6$; $a:b:c = 1.732:1:1.271$	91	Homogeneous	
δ	Ni_2Si	19.3	Orthorhombic	$a = 7.39_2$, $b = 9.90_2$, $c = 7.03_6$; $a:b:c = 0.6465:1:0.7106$	48	Homogeneous	
θ	Ni_2Si	23.0	Hexagonal	$a = 3.7970$, $c = 3.892_8$, $\frac{c}{a} = 1.290_7$	6	Homog. after quenching from 2000 °F.	The distribution of lines is same at low and high temperatures
ε	Ni_3Si_2	24.3	Orthorhombic	$a = 6.605_4$, $b = 7.627_2$, $c = 9.574_0$	45	Almost homogeneous	
η	NiSi	32.5	Tetragonal	$a = 7.653_8$, $c = 8.451_4$, $\frac{c}{a} = 1.104_4$	40	Almost homogeneous	
ζ	$NiSi_2$	49.0	Rhombohedron	$a = 8.881$, $\alpha = 90°23.6'$	54	$Si + \zeta + \eta$	Weak lines of Si appear
ζ'	$NiSi_2$	49.0	The lines of Si and ζ appeared strongly in the specimen quenched in ice water from 1880 °F.				
Si		About 100	Cubic (diamond)	$a = 5.409_3$	8	Homogeneous	Probably 1 to 2 % of Ni is soluble at high temperature

Letters from Abroad

Collapse of the Hasselt Bridge

Letter from Albert M. Portevin
Professor, Ecole Superieure de Fonderie

PARIS, FRANCE — On March 14, 1938 the Hasselt Bridge collapsed into the Albert Canal in Belgium. It was of the all-welded Vierendeel type, 250-ft. span, constructed of plates of mild steel made in basic converter, tensile strength 60,000 to 70,000 psi., elongation 20 to 24%. As shown in the photograph on the next page the breaks were clean with no jagged edges, elongation or necking; no part seems to have sagged or become deformed; the breaks were found to extend through both the welds and the parent metal without favoring one or the other.

The bridge was still in the water and no sample had yet been removed and examined or tested before opinions and verdicts were freely rendered in words and in writing, all the more assertive and peremptory that no experimental proof was brought in support of them. By assembling all of these opinions it is possible to make a complete collection of all possible causes. The various factors blamed were:

1. The metal: Thomas steel — a steel made in a basic-lined converter, and said to have little ductility, or capacity for flow under the welding heat, and possibly non-weldable as well.
2. Design: Type of construction, rigidity of the bridge members, use of welding, calculations made without taking into account residual stresses.
3. Construction: Poor welding procedure both in shop and field, use of large electrodes generating local defects, poor sequence in assembling the members, exaggerated residual welding stresses.
4. Aging of the steel at the weld.

The above include only the published opinions and assertions. It is obvious, since almost all the possible causes of the accident are enumerated in this list, that some of the authors are consequently right. Moreover, since most accidents occur only as the result of the superposition of several errors and of the interaction of several causes, we can see that in this lottery there will be more than one winner who will glory in his perspicuity, which is really only shallow-mindedness, for no true technical man should utter an opinion without thorough study and an expert survey in which all the positive data have been collected and verified.

Moreover, not a few false opinions will have been publicly propagated and will have unjustly discredited fabrication processes or construction conditions perfectly capable of good use if certain well-known rules are observed.

Consequently, there results not only a regrettable loss of time, but also a propagation of errors prejudicial to technical progress. The writer has himself had occasion, in the course of making technical surveys of accidents such as the failure of the Lac Noir conduit, to ascertain how many false opinions were circulated among the general public, and even among technical men. It must not be forgotten either that among the numerous causes that may be assigned *a priori* to an accident, each person who has been connected with the work prefers to choose and publicize that cause which minimizes his own responsibility.

In this accident, as in others, we should await the conclusions of the commission appointed by the Belgian Government to inquire into the causes. It would then be very desirable (and it is not always done) to give the utmost publicity to its conclusions so that they may be taken into consideration in preventing the recurrence of such accidents.

Determining the responsibility is of little importance from the general standpoint of progress and technical security, while establishing the causes and above all indicating the remedies is a useful and fecund labor.

As soon as these causes are elucidated by the Commission of Inquiry we shall not fail to make them known. Meanwhile, we can best recall certain general rules which, though they may not be the primary cause of the accident,

Fractures at Hasselt Bridge, Showing no Apparent Ductility. (Members had webs and flanges of plates, welded together.) Photo by M. Maréchal.

should be conformed to by welding engineers:

1. The metal used should be examined as to its weldability, not only for local or metallurgical weldability but also for structural weldability. The test for local weldability is made on separate test specimens and determines the reaction to stresses *after* welding; the test for structural weldability is made on assemblages to determine important internal stresses and the resistance of the weld to high temperature — it determines the reaction to stresses *during* welding.

2. In executing the work, the directions in which the welding is done must be symmetrically placed and distributed along the length or axis of the assembly; the assemblages should be so arranged that transverse shrinkage in each one may have free play; large concentrations of welds and members of variable rigidity should be avoided. If there are any doubts as to the extent of internal stresses, their presence or absence should be verified in the welded structure, even if this necessitates sectioning it, measuring the ensuing movements, and then rewelding.

ALBERT M. PORTEVIN

New High Speed Steels

Letter from H. HOUGARDY
Research Laboratories, Deutsche Edelstahlwerke

KREFELD, GERMANY — Developments in high speed steel have ordinarily relied on alloy content for a criterion of steel quality. This explains, in the final analysis, why tungsten was continually increased from the air-hardening Mushet steels to the first Taylor-White high speeds. For the same reason cobalt was added in the course of a year, and then vanadium was added in higher percentages, likewise improving the cutting efficiency.

However, after more accurate information was secured on the nature of the high speed steels and the appropriate heat treatment for each steel was established, it became apparent that the *amount* of alloy is not the decisive factor in judging high speed steel. A far better criterion is the actual cutting life of a standard tool. This knowledge contributed substantially to the introduction of several new high speed steels in Germany, which were created first as an outcome of this general enlarging of our information, and second because a shortage of certain raw materials, especially tungsten, curtailed the use of this metal.

New German High Speed Steels

Efficiency Group	Newer Tungsten Steels (Chromium 4%)			Older Steels Comparable in Cutting Efficiency		
	% W	% Mo	% V	% W (max.)	% V	% Co
A	10 to 12	1.0 max.	1.0 max.	18	0.8 max.	...
B	10 to 12	1.0 max.	1.5 max.	18	1.2 max.	...
C	12 to 13	1.0 max.	2.0 max.	18	1.8 max.	...
D	12 to 13	1.0 max.	2.7 max.	18	1.8 max.	...
E	13	2.0 max.	1.7 to 5.0	18	2.5 min.	2.5 min.
	New Molybdenum Steels					
B	2.0	8.0	1.2	18	1.2 max.	
B	3.0	3.5	3.0			
D	6.0	4.5	2.7	18	1.8 min.	

Our high speed steels today are classified in two groups — *(a)* the tungsten steels and *(b)* the molybdenum steels. The first table shows typical compositions of the steels now in common use in Germany and classifies them into groups as to cutting efficiency, so they can be compared with the steel formerly prevalent. (It is understood, of course, that the chromium remains constantly at or about 4%.)

It is apparent that the tungsten content in all steels can be limited to 10 to 13%. Likewise the cobalt steels do not need so high a tungsten content to produce equivalent tools. The steels with vanadium were even earlier reduced to 12% tungsten, since it was found that the same cutting efficiency was obtained, especially in roughing cuts.

To trace the development of the molybdenum alloy steels we can, on the one hand, go back to German investigations made during the years 1914 to 1923 when attempts were made to substitute molybdenum for tungsten, or on the other hand we can credit more recent experiments in the United States on molybdenum alloy steels, which have been carried to such fruitful conclusion here. As an example of the fact that a tool with 12% tungsten is capable of the same cutting efficiency as one with the same vanadium and molybdenum content and 18% tungsten, see steels No. 1 and 2 of the second table. If we go a little further and simultaneously raise the vanadium and molybdenum content somewhat, we obtain a cutting life double that of a steel with 18% tungsten (compare steel No. 3 with No. 4).

In the three new molybdenum steels of the first table the molybdenum runs between 3.5 and 8%, although in other analyses the tungsten and molybdenum content may vary from these figures. No tungsten-free steels have been manufactured, for it has been demonstrated without doubt that tungsten-free steels possess a short service life. On the other hand, the tendency among makers of the leading molybdenum steel tools has been to specify a minimum content of molybdenum as well as vanadium. The life of these steels is comparable to that of standard 18-4-1 (18% W, 4% Cr, and 1% V).

Cutting Efficiency of Tungsten High Speed Steels

Steel No.	Composition *(a)* % C	% W	% V	% Mo	Tool Life in Min. *(b)*
1	0.77	10.93	0.99	0.70	40
2	0.75	18.40	0.98	0.55	39
3	0.79	11.70	1.35	0.68	57
4	0.76	19.02	0.79	0.20	28

(a) Chromium in all, about 4%.

(b) Cutting plain carbon steel of 100,000 psi. tensile strength; depth of cut 0.120 in.; feed 0.036 in. per revolution; cutting speed 60 ft. per min.

However, it has further been established that by varying the tungsten, molybdenum and vanadium content even within very slight limits, a pronounced change in cutting efficiency can be obtained. The third table shows the results of tests to determine the effect of changes in alloy content. Steel No. 5 represents a standard 18-4-1 steel. If the tungsten content is lowered to 6% and the vanadium content raised to 4.5%, necessitating a simultaneous increase in carbon content, then the cutting life obtained is only half that of the 18-4-1 steel (steel No. 6). If 1% molybdenum is added, permitting a simultaneous decrease in vanadium content to 2.5%, a cutting life comparable to the 18-4-1 steel is again obtained (steel No. 7). Further increase in molybdenum content again raises the cutting life considerably (steels No. 8 and 9). A simultaneous decrease in tungsten content again lowers the cutting life (steel No. 10), which, moreover, cannot be restored by raising the molybdenum content (steel No. 11). Complete absence of tungsten gives a minimum cutting life (steel No. 12).

Cutting Efficiency of Various High Speeds

Steel No.	Type	Composition *(a)* % C	% W	% V	% Mo	Tool Life in Min. *(b)*
5	18-4-1	0.75	18.40	0.98	0.55	30
6	Molybdenum-free	1.43	5.89	4.52	...	17.5
7	Steel 2 plus Mo	0.81	5.60	2.37	1.05	35
8	High molybdenum	1.07	4.22	2.85	4.26	57
9	High molybdenum	0.92	3.98	2.29	4.08	57
10	Low tungsten	0.93	2.47	2.63	2.86	36
11	Low tungsten	0.99	1.96	2.80	3.40	25
12	Tungsten-free	1.10	...	3.18	3.42	19

(a), *(b)*. See footnotes to other table.

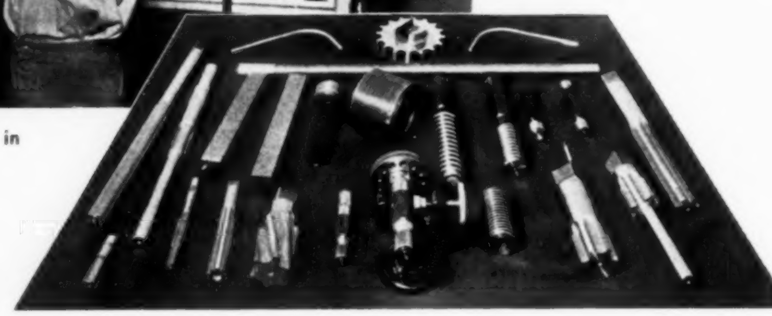
It is thus clearly evident that molybdenum cannot be substituted for *all* of the tungsten, but that the elements tungsten, molybdenum and vanadium must be specified in proper proportion, in addition to about 4% chromium, if optimum cutting life is to be obtained, assuming always that each steel tool is properly fabricated and heat treated.

H. Hougardy

"Certain Curtain" hardening and pre-heating furnaces in action on high speed steel at John Bath & Co.

BATH TAPS

Ground from the Solid After Hardening



Ground from the solid after hardening, Bath tools have established a reputation for long cutting life.

"We feel we are now developing the working qualities of our steel to the highest degree,"

—states John Bath & Co.

Protection of tool surface is usually thought of as the chief function of "Certain Curtain" control of furnace atmosphere.

Yet here is a maker of ground-from-the-solid tools of high speed steel, who is definitely enthusiastic about "Certain Curtain" hardening. Why? Because this precision control of atmosphere is important to sub-surface structure, as much as in protection of surface.

"The big thing about your furnaces from our point of view," states John Bath & Co., "is the sureness with which we can predetermine results, and the ease with which we obtain these results consistently. With our former equipment, we were producing good hardening results, but it required a great deal of time and care to secure the desired hardness and grain structure.

We are now able to keep our hardness uniformity within ½ point tolerance, and in addition we get an improved structure: fine grain with slight boundary and good carbide solution. We feel that we are now developing the working qualities of our steel to the highest degree."

– – –

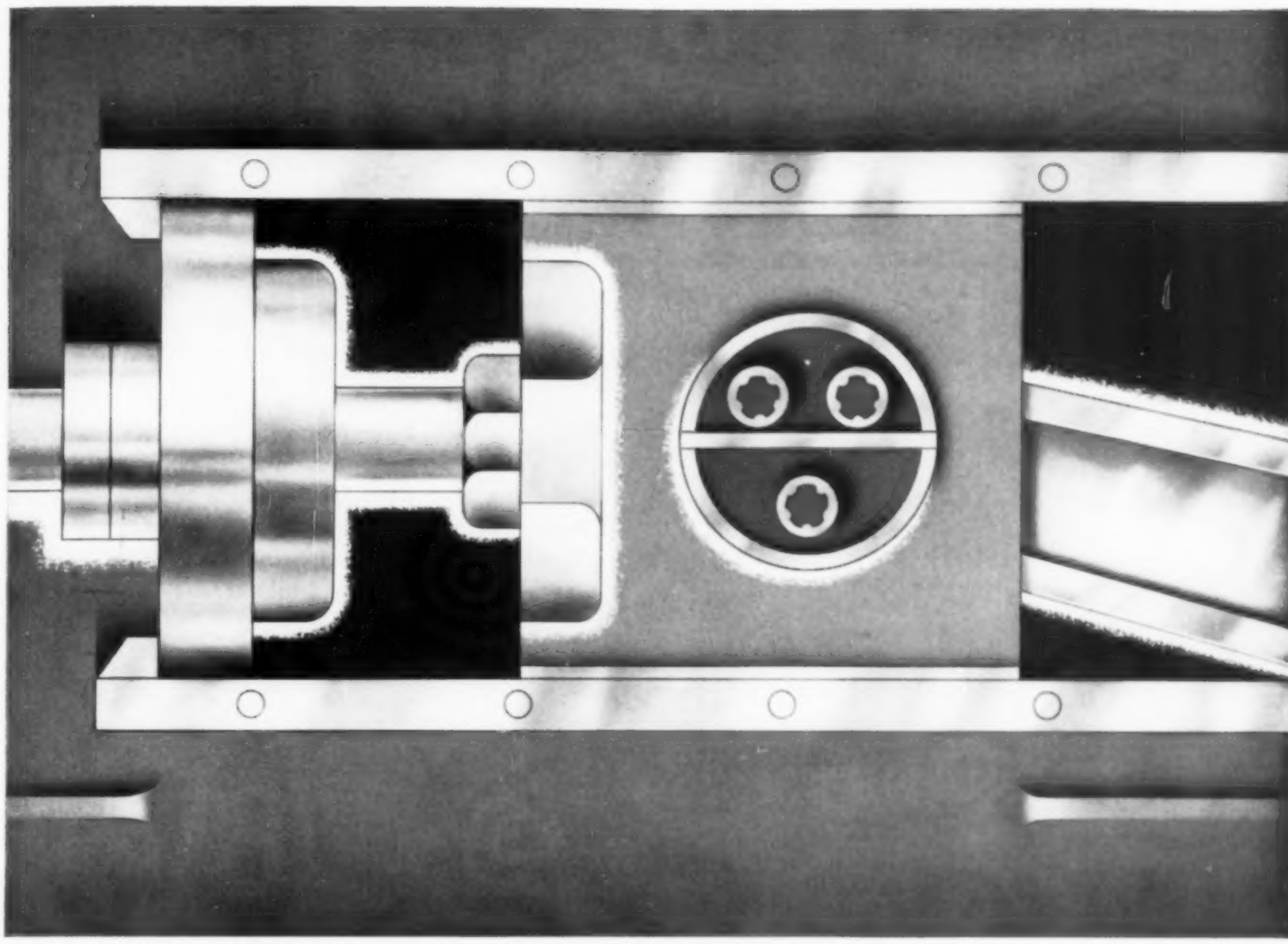
In the above plant, two Hayes furnaces handle a volume of work which formerly required FOUR fuel furnaces! And in other plants using 1,000 "Certain Curtain" furnaces the world around, the experience is similar: tools with improved working life, produced at lower cost. Request new Bulletins 12 & 105. C. I. Hayes, Inc., Est. 1905, 129 Baker Street, Providence, R. I.

5 points explaining "Certain Curtain" leadership

1. "Certain Curtain" performance accepted as The Standard, even by other makers who often claim "as good as 'Certain Curtain'."
2. Through definite savings in tool cost, these furnaces frequently repay their cost in 6 to 18 months.
3. With approximately 1,000 furnaces in the U. S. and 16 foreign countries, "Certain Curtain" is literally the world leader.
4. The patented basic principle of "Certain Curtain" atmosphere control remains unchanged, while scope has greatly widened through adaptation and mechanical refinements.
5. After 11 years, with new methods coming and going, "Certain Curtain" is more firmly established than ever as THE LEADER among controlled-atmosphere furnaces.

ELECTRIC CERTAIN CURTAIN FURNACES
REGISTERED U. S. PAT. OFFICE

FOR 11 YEARS THE LEADER IN CONTROLLED-ATMOSPHERE HEAT TREATMENT



Personals

Norman A. Matthews has been assigned for a year to the Research Laboratory of United States Steel Corp. at Kearny, N. J., after which he will return to the metallurgical department of National Tube Co., Lorain, Ohio.

Horace Y. Bassett is now with Wolverine Tube Co., Detroit.

Albert A. Frey is now with Wheeling Steel Corp. as special metallurgist on electrical sheet steels.

William D. Poole has been appointed metallurgical supervisor of the sheet, tin and strip division of Bethlehem Steel Co.'s plant at Sparrows Point, Md.

Ellis A. Walker is now with Republic Steel Corp. at the Buffalo plant.

Transferred by Republic Steel Corp.: **Ralph W. Farley**, from electric weld tube mills in Youngstown to Houston, Texas, as field representative on tubular goods.

James L. Sutherland, O.S.U. 1939, is now working in the metallurgical department of Youngstown Sheet & Tube Co., Youngstown, Ohio.

Added to technical staff, Battelle Memorial Institute, Columbus, Ohio: **Arthur E. Bearse**, chemist, formerly with Arthur D. Little, Inc., and **Howard Peters**, metallurgist, formerly with Central Indiana Gas Co.

William K. Kellogg has been transferred from the Sanderson plant at Syracuse, N. Y., of Crucible Steel Co. of America to the Chicago office in the sales department.

Johnston Kingsley has been transferred by Crucible Steel Co. of America from Pittsburgh to Harrison, N. J.

Edwin R. Richards is now assistant superintendent No. 3 openhearth and bessemer, Carnegie-Illinois Steel Corp., Chicago.

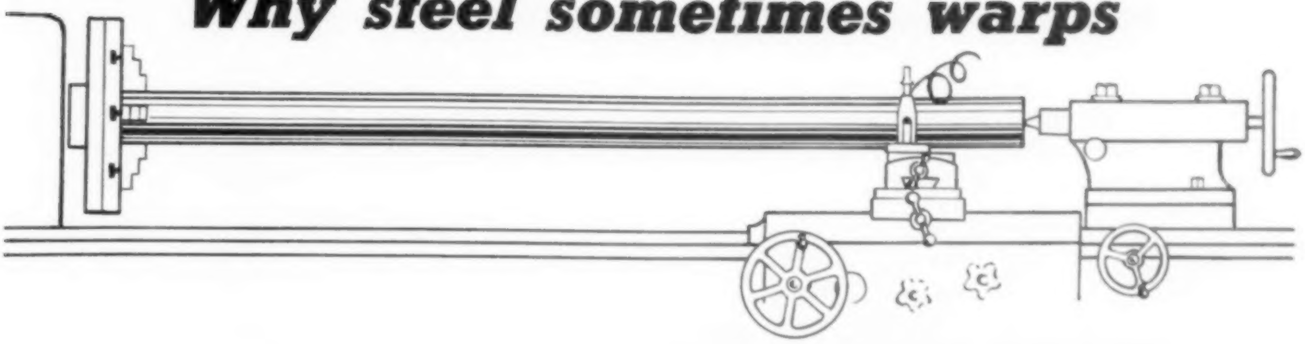
Promoted by Inland Steel Co.: **Ervin J. Sanne** to assistant manager of sales in the sheet and strip steel division, Chicago; **Frederick A. Ernst** to district sales manager at St. Paul; **Harry A. Johnson** to assistant district sales manager at St. Paul.

Donald M. Yenni is now with Spencer-Smith Machine Co., Howell, Mich.

Thomas J. Wood, formerly with the foundry division, Robins Conveying Belt Co., Passaic, N. J., is now assistant metallurgist for American Brake Shoe & Foundry Co., Mahwah, N. J.

Now Chicago representative of the Ohio Crankshaft Co.: **Leslie C. Schweitzer**, formerly of Westinghouse Electric & Mfg. Co.

Why steel sometimes warps



Stress-relief anneal will usually prevent it

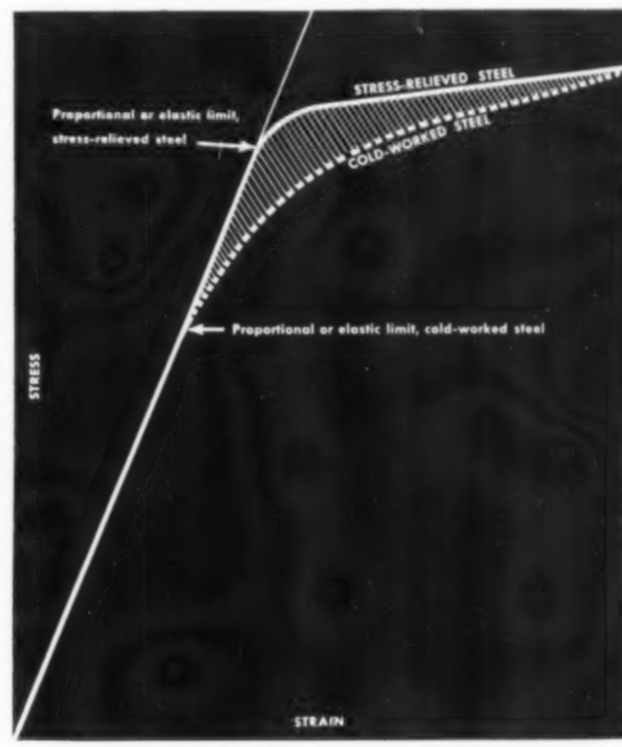
FROM time to time machine shops complain of warpage or distortion when machining steel bar stock. This is usually noticeable only when the part is long. It occurs on "as-rolled" or heat-treated bars which have been machine straightened and on cold-drawn bars, especially where key-ways are cut. The harder or stronger the material, the more likelihood of trouble.

Cause. The cause is not a defect in the metal, but rather stresses set up within the steel by straining it beyond its elastic limit. Machine straightening a bar will do this, as will cold forming or cold drawing. Even the cold working that the steel receives by heavy machine cuts may be the cause of such warpage.

Remedy. The remedy is to relieve such stresses before machining (or between machining operations, if heavy cuts are taken). This can usually be accomplished by a low-temperature or stress-relief anneal.

Such an anneal will usually be carried out at a temperature between 800 and 1100 deg. F. Obviously, on quenched-and-tempered parts, the temperature should be held approximately 100 deg. F. below the tempering temperature to avoid softening the steel.

Effects of this sub-anneal. A stress-relief anneal will have no harmful effects on the steel. To a limited extent it may improve the physical properties. Note the curve above. The elastic limit, or point where the stress-strain curve leaves a straight line, is lowered by cold-working steel. A stress-relief anneal will raise this point until it approaches the yield point. Little difference will be noticed either in yield point or tensile strength. Ductility, if changed, will be improved.



Effect of stress-relief anneal (shaded area). It raises the elastic limit without noticeably affecting yield point or tensile strength

Metallurgical advice. A call to the nearest Bethlehem office, or a letter to Bethlehem Steel Company, Bethlehem, Pa., will bring metallurgical advice on this or other subjects. To make use of this service places you under no obligation.

BETHLEHEM STEEL COMPANY

Personals

Ted Barker, founder member, formerly president, Accurate Steel Treating Co., is now proprietor of the Atascadero Motor Lodges at Atascadero, Calif.

Tom Addison has been named chief designing engineer for Defiance Machine Works, Defiance, Ohio.

Carl H. Bjorquist is now an associate engineer with the U. S. Department of the Interior on the Bonneville Project at Portland, Ore. For about a year he will travel in the East as technical inspector of materials and equipment being purchased for the project.

C. R. MacBride has been appointed manager of the engineering service department, A. M. Byers Co., Pittsburgh.

Promoted by American Steel & Wire Co.: **Walter F. Munford**, formerly superintendent Cuyahoga Works, to assistant to vice-president (operations) at the main office in Cleveland; **H. L. Jenter**, formerly assistant superintendent, to general superintendent, Cuyahoga Works; **R. H. Barnes**, formerly district metallurgist in Cleveland, to division metallurgist on flat rolled products and strip; **J. E. Millen**, formerly in charge of statistical work in the Cleveland district physical laboratory, to assistant division metallurgist on standard practice.

William J. O'Sullivan, junior aeronautical engineer, has been appointed for probational duty at Langley Field, Va., in the Flight Research Division of National Advisory Committee for Aeronautics.

Among the nominees for directors of the Gray Iron Founders' Society, Inc. are **C. R. Culling**, vice-president, Carondelet Foundry Co., St. Louis, and **Peter E. Rentschler**, president, Hamilton Foundry & Machine Co., Hamilton, Ohio, for three year terms; and **C. A. Cullinan**, president, Western Foundry Co., Chicago, and **A. C. Denison**, president, Fulton Foundry & Machine Co., Cleveland, for one-year terms.

B. B. Beckwith, formerly with Chrysler Motor Corp., has joined the metallurgical staff of Vanadium Corp. of America with headquarters in Detroit.

Bradley Stoughton, national treasurer, head of department of metallurgical engineering, Lehigh University, has been elected an honorary member of the Yale Engineering Association.

Appointed by the Carborundum Co.: **John Storm**, as district sales manager at New York City, succeeding **Frank J. Harrington**, transferred to the sales department at the main office in Niagara Falls, N. Y.

Structure of Atoms

By G. P. HARNWELL

Extracts from "Our Knowledge of Atomic Nuclei", Journal, the Franklin Institute, April 1939, p. 443

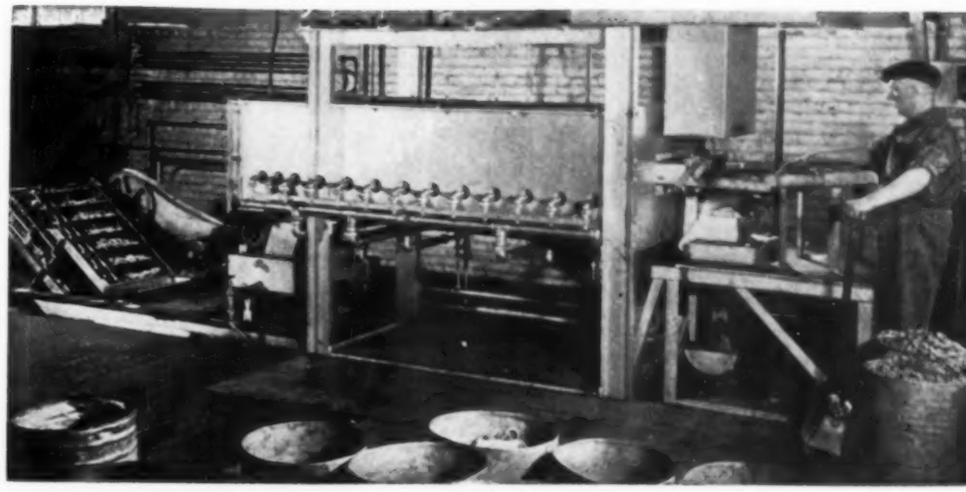
THE SUBJECT WHICH WITHIN THE PAST few years has come to be known as "nuclear physics" is an outgrowth and in many ways the culmination of the research in atomic physics which began with the opening of the present century. As a result of these earlier researches, especially on radioactive materials, it was concluded that an atom contained a characteristic number of "electrons" but that the massive portion was concentrated in a very minute region at the center of the space occupied. The "diameter" of this central mass or nucleus is of the order of a hundred-thousandth the "diameter" of the atom as a whole. The general relative scale and tenuousness of an atomic system is similar to that of our solar system where the central sun, though much smaller then the outermost planetary orbit, comprises most of the mass. These facts and the additional one that radioactive emanations are given off in a statistically predictable way were all that was known of the matter up to 1919.

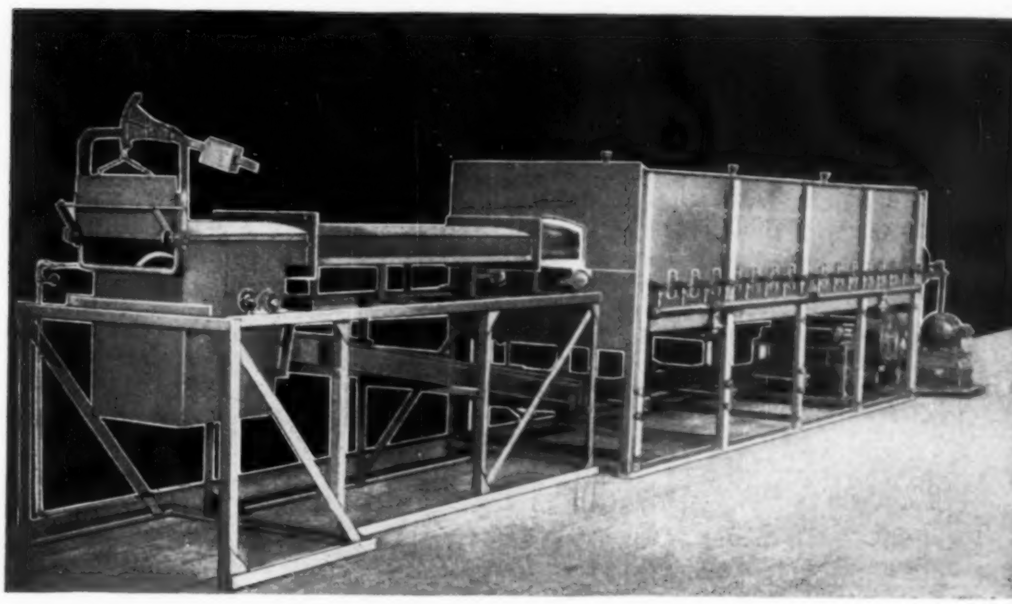
What is an electron? All we know about it is that there is a characteristic minute invariable electric charge associated with it and that it has an effective mass which is about a two-thousandth that of the hydrogen atom, the lightest one known. Furthermore, it acts as if it were a minute electrically charged spinning top, for it possesses angular momentum and a magnetic moment. In addition to these facts, we know very roughly indeed the volume of space it occupies, and that is absolutely all we know about its size and shape.

How are the electrons and the more massive constituent or constituents held together to form an atom? As these two components have opposite charges and we know opposite electrical charges "attract" one another, we have here one possible type of force. Our investigations have shown that there are other types of which we know very little. In the first place, the identical nature of the electrons apparently gives rise to forces between them. In addition the spinning or vortical motion that appears to be associated with these elementary particles gives rise to spin forces of interaction in somewhat the same manner as two smoke rings can be bounced from one another. The fact that I cannot describe these forces better shows that we have much to learn about them.

Information concerning the well-guarded nucleus awaited the discovery in 1930 that we can accelerate charged atoms of hydrogen and helium in electric fields until they (Cont. on page 502)

AMERICAN GAS FURNACE CO.
PIONEERS IN 1878
LEADERS TODAY





Above: Continuous clean hardening in Reciprocating Full Muffle Heating Machine under atmospheric control.

Left: Continuous "NI-CARB" surface hardening without quench for a uniform, thin, hard case.

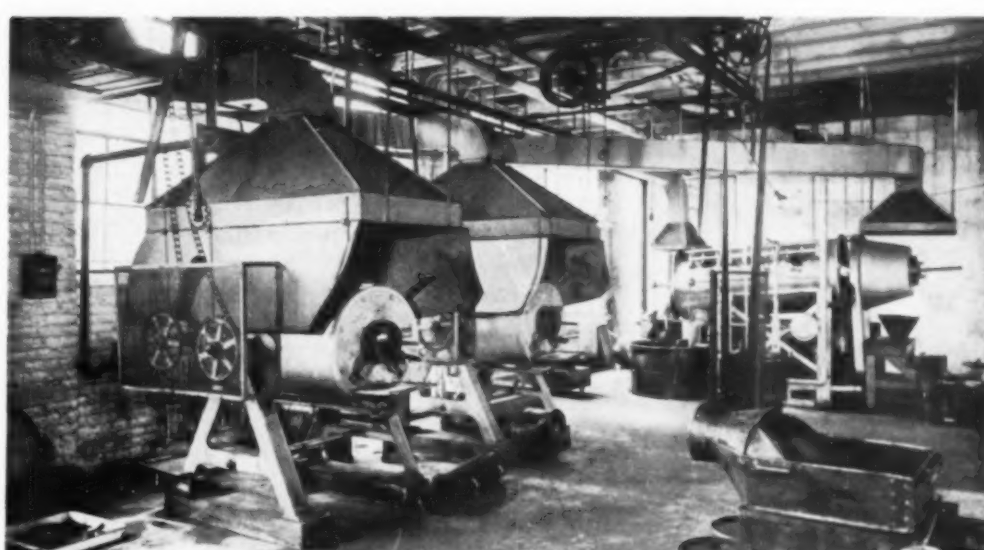
Below: Continuous clean hardening in Rotary Retort Machine with atmospheric control, also rotary tempering and gunmetal finishing.

Modern Equipment

for

Continuous or Batch
Gas Carburizing
Clean Hardening
Clean Annealing
"Ni-Carbing"
Nitriding
Normalizing

——Write——



American Gas Furnace Co., Elizabeth, N. J.

Atom-Structure

(Cont. from p. 500) gain sufficient speed to disintegrate other atoms that they encounter. These particles available in large quantities and with controllable speeds are the chief agents of modern research in this field. Within two years was proven the existence of a hitherto unsuspected atomic particle with a mass closely the same as that of hydrogen but incapable of acquiring an electric charge. Hence this received the name "neutron". A new, very light electronic particle was also found, having a characteristic positive charge and therefore called "positron"; it might be thought of as the opposite of the electron which had been known for 30 years or so.

The fundamental and as yet indivisible particles that have been discovered by research and of which the nucleus of all atoms is probably composed in various proportions are the proton, which is the hydrogen nucleus, and the neutron. When recited baldly our knowledge of these particles does not seem extensive. We know their masses (which are closely the same) and their electrical characteristics, the proton having a characteristic positive charge and the neutron none at all. We also know very roughly the volume of space they occupy and that they have certain characteristic angular momenta, that is, they behave somewhat like minute spinning tops. As the proton has a charge and is rotating, we would expect it to behave like a small magnet which indeed it does, and somewhat to our surprise the uncharged neutron also appears to have magnetic properties. This is all we can say about these particles except that there are apparently forces between them that bind them into complexes that we call the nuclei of the atoms of all the different elements.

These forces apparently have no analogues in our large-scale world.

The simplest nucleus is that of hydrogen which is the proton itself. Then comes the nucleus of heavy hydrogen which is composed of one proton and one neutron. The combination of three of these particles appears for some strange reason to be relatively loosely held together or fragile, for we do not observe it in nature. The helium nucleus which is formed of two protons and two neutrons is a particularly strong and compact structure. The next lightest atom, that of lithium, is composed of three protons and either three or four neutrons and so on through the entire periodic table till we reach uranium, which is composed of 239 of these units, 92 being protons and the balance neutrons. (Cont. on page 506)

Atom-Structure

(Continued from page 502)

By bombardment of ordinary chemical elements with atomic and subatomic particles and by light of ultra short wave length we have been able to make many new kinds of atoms which are not stable but throw off a light fragment or absorb one of their surrounding electrons, thus forming again a stable configuration — that is, we are able to produce radioactivity in a number of elements, and this is of the utmost practical importance.

The direct therapeutic effects of the radioactive variants of ordinary elements are the same as those of radium and if there were no other result than the production of large amounts of equivalent radium it would be one of the most important discoveries ever made. As a single instance of its application, the thyroid gland is known to have the property of assimilating iodine. It is possible to render iodine radioactive in such a way that it decays with a mean life of about 25 min. with the emission of ordinary electrons. Thus radioactive iodine injected into the body will tend to be localized in the thyroid gland. Also the atom resulting from the emission of the electron is no longer radioactive and peculiarly inert chemically; this removes any possible hazard from the treatment. In a similar way phosphorus and calcium which are bone constituents may be rendered radioactive, and enable the physician to localize radioactivity in the bony structure.

The applications in the closely associated field of physiology are of equally great interest. As it is easy to detect the presence of a very minute number of radioactive atoms among a great number of the ordinary variety characteristic of the element, it is possible to prepare samples of elements that retain their identity and may be followed through physiological reactions. It has been reported that long-lived radioactive carbon atoms can be prepared. These may form molecules of organic compounds which can then be followed through the body, opening up a new and highly important field of biological research.

Radioactive "tracer atoms" may also be used in metallurgy and the physics of solids to study the diffusion of atoms through single crystals and across and along crystal boundaries. Studies of this sort under various conditions of temperature and strain should clarify many of the problems that are now presented by the solid state and lead to alloys with more desirable properties for various applications.

Fretting Corrosion

(Continued from page 468) heard as faint clicks.

Surfaces of clean brass against hardened steel both appeared to be corroded, but it seemed possible that all the red debris might have been detached from the brass and merely plastered over the steel. However it proved impossible to remove the corrosion effects with a knife. There is little doubt, therefore, that the soft brass has been able to fret its way into hard steel.

In order to control better the amount of slip, and to study the effect of variable pressures, a device was constructed which caused small oscillations of a $2\frac{1}{2}$-in. sphere or a blunt cone between two loaded horizontal plates. Magnitude of motion under the sphere increases from zero at the direct center of contact, and after all experiments there was a central unaffected spot (where surface motion was elastic) and a sharply defined annular fretted zone where the tangential displacement involved some slip. Other experiments with the blunt cone indicate that there is no kind of proportionality between the pressure and the damage to the surface, and that the effect is independent of the speed of reversal.

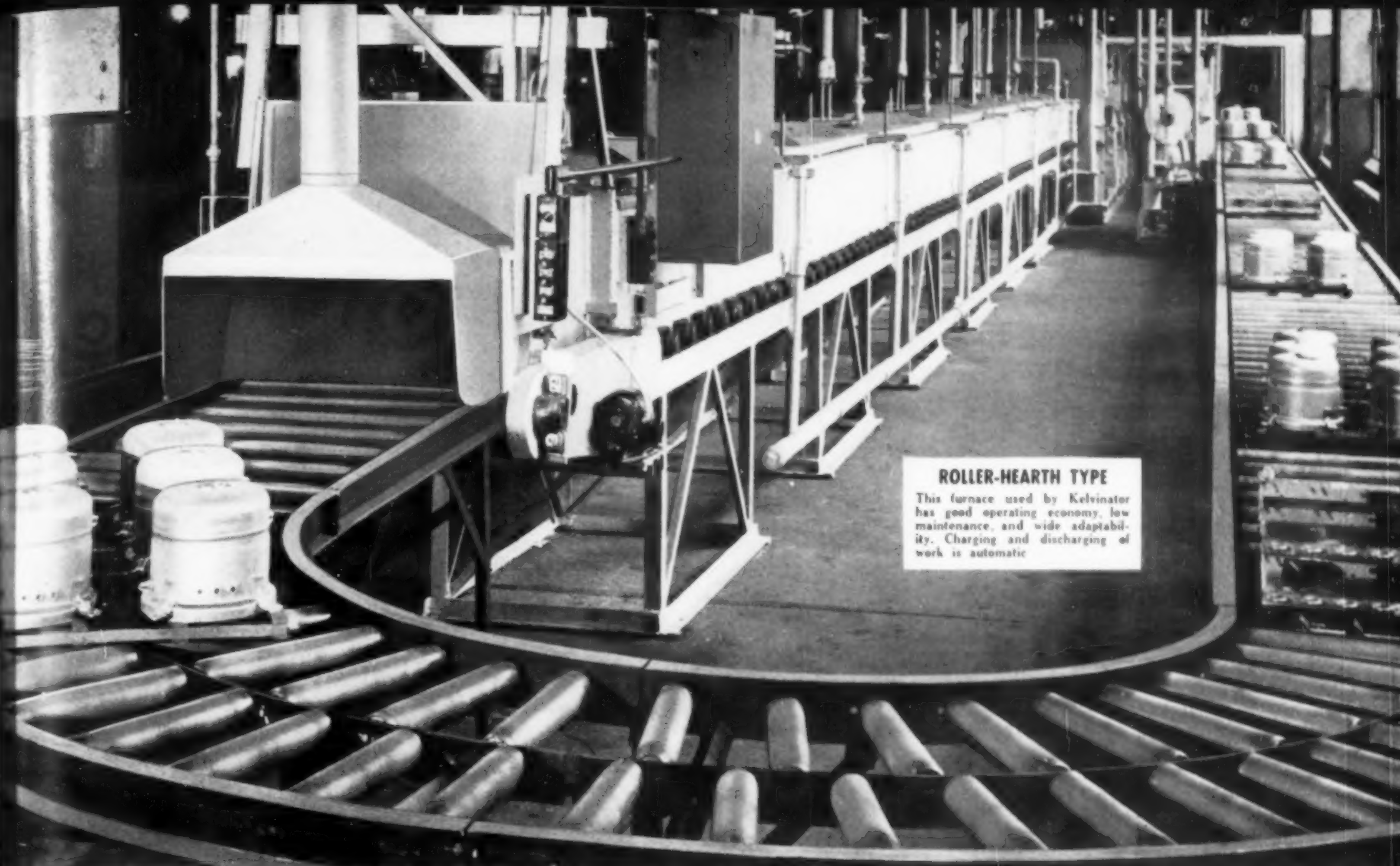
A series of tests has been carried out in which only the nature of the material has been varied. The materials included hardened steel, mild steel, stainless steel, brass, nickel, chromium, "Y" alloy, and glass. In every case 100,000 reversals of slip on the order of 1×10^{-6} in. produced visible corrosion. In the case of glass the term "corrosion" is hardly appropriate. The appearance of the glass plate under the microscope is that of small glittering patches with no sign of corrosion debris.

The first point of general interest in these experiments is that there is not a single instance of no corrosion. The "Y" alloy versus chromium plate comprise a very soft and an extremely hard metal in contact, and there is little doubt that the chromium has been fretted away.

The combinations in which one material is brass definitely produce the minimum amount of corrosion, while stainless steel in any combination appears to be the worst material in this respect.

A similar series of tests has been made of the corrosion of a variety of pairs of different materials lubricated with castor oil and with a high pressure lubricant. These lubricants reduce the rate of corrosion, but do not prevent it.

The results of the investigation are not as encouraging as would be desired. If the theoretical conclusions are valid, the corrosion must be placed in the class of molecular phenomena and as such may have to be regarded as being inevitable like cohesion or friction.



ROLLER-HEARTH TYPE

This furnace used by Kelvinator has good operating economy, low maintenance, and wide adaptability. Charging and discharging of work is automatic

NOW KELVINATOR TURNS TO G-E FURNACE BRAZING FOR IMPROVED PROCESSING

THE reasons for Kelvinator's choice of a G-E roller-hearth furnace for brazing refrigerator subassemblies are found in the following general benefits:

Increased life of subassemblies and reduced service costs because of greater strength of the finished product.

Reduced production costs because of savings in time, material, weight, rejections, and inspection.

High productivity because many joints in each assembly can be brazed at one time.

Flexibility because light and heavy parts, and like and unlike metals, can be joined.

Other benefits: *Clean, bright surfaces, uniform tightness,* and *excellent appearance.*

YOU CAN GET THESE ADVANTAGES

General Electric builds a complete line of brazing furnaces—there's a type and size that will meet your requirements. The long life of the heating elements and other furnace parts and the low current consumption made possible by generous heat insulation make these G-E furnaces very economical to operate.

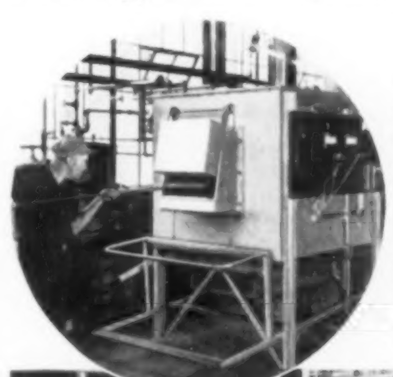
If you wish, you can check the possibilities of electric-furnace brazing on your own samples in our Industrial Heating Laboratory. Get in touch with a G-E heating specialist—he will make arrangements for you.

WRITE FOR BOOKLET—NOW BEING PRINTED

Send your name to General Electric, Dept. 6—201, Schenectady, N. Y., and we'll mail you a 50-page booklet "How and Where to Use Electric-furnace Brazing" (GEA-3193) as soon as copies are available.

See the G-E "House of Magic" at Both Fairs

Other Types of G-E Brazing Furnaces



BOX TYPE

Excellent for small-scale or intermittent furnace brazing. Can also be used for scale-free hardening and bright annealing

MESH BELT

Built for continuous production of relatively large quantities of work, these furnaces are copper brazing and annealing miscellaneous assemblies

GENERAL ELECTRIC PROVES FURNACE PERFORMANCE BY LABORATORY TESTS

GENERAL ELECTRIC

160-83

Control of Lead

(Continued from page 463) likely to be a health hazard, but in the manufacture of lead-bearing steels there is a much lower exposure, and therefore less of a health hazard, than that which exists in many other industries. The lead can be controlled at relatively low cost by methods already well developed in other established industries, so an enlightened management can protect its workmen adequately. The benefits to man of such steels may be obtained without any great danger to his health.

A succeeding article will treat the problems raised by lead in the plants of the users, during such operations as welding, burning and handling. It will show that the health hazard is limited and can be controlled at little cost.

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